SOUNDING
THE OCEAN OF AIR

THE ROMANCE OF SCIENCE.

SOUNDING THE OCEAN OF AIR

BEING SIX LECTURES

DELIVERED BEFORE THE LOWELL INSTITUTE OF BOSTON
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BY

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This little Book is gratefully Dedicated

TO

THE LATE AUGUSTUS LOWELL, ESQ.

OF

BOSTON, U.S.A.

WHO, AS TRUSTEE OF THE LOWELL INSTITUTE,
ENABLED SCIENTIFIC MEN OF TWO CONTINENTS TO
PRESENT THE RESULTS OF THEIR INVESTIGATIONS
TO THE PUBLIC

CONTENTS

CORRIGENDA

Page 50, line 11, *for* "isolation" *read* "insolation."

Page 59, line 21, *before* "direction" *insert* "opposite."

Page 112, line 2; page 115, lines 2 and 15, and Index, pages 175 and 183, *for* "Viollé" *read* "Violle."

Page 112, line 23; page 113, line 6, and Index, page 181, *for* "Muntz" *read* "Müntz."

Page 123, last line, *for* "1889" *read* "1891."

Index, page 177, *for* "Cotte (T.)" *read* "Cotte (L.)."

Index, page 179, *after* "Hann (J.), 36," *add* "173."

Index, page 179, *for* "Hellman (G.)" *read* "Hellmann (G.)."

Index, page 181, *after* "Langley (S. P.)" *insert* "28."

CONTENTS

LIST OF ILLUSTRATIONS

SOUNDING THE OCEAN OF AIR

CHAPTER I

THE ATMOSPHERE—ANCIENT AND MODERN KNOWLEDGE—METHODS OF INVESTIGATION

CONCERNING this most important element in which we live and move and have our being, Pliny, in the first century of our era, wrote as follows: "It is time to consider the other marvels of the heavens; thus our fathers called that immense space where flows the vital fluid to which we give the name of air, and which is not apparent to the senses because of its great rarity. There clouds form, thunder and lightning also; it is the region of tempests and of whirlwinds; from there fall rains, hail, and hoar frost; from there come all those phenomena, astonishing and often disastrous, which follow the combat of Nature with herself. . . . The sun's rays strike the earth on all sides, warming

and strengthening it ; they are reflected and detach all the particles they can carry away; vapours descend and rise again ; the winds come empty and return laden with spoil ; animals breathe in from above this vital fluid which animates them, and the earth sends it back to its source as if she would fill the void by this means. So, by Nature acting everywhere and in all directions there results an apparent discord from which is born the harmony of the Universe; it is this general movement which puts all things in their places ; some are preserved by the destruction of others ; all move, all act, the struggle is continual, if it ceased an instant everything would fall into chaos. . . ."

From the earliest times, as far back as history extends, we find mankind interested in meteorological phenomena. This appears natural if we consider the importance of the weather to the ancient pastoral nations, which, from the open-air life and keen perceptive faculties of their people, were well fitted to study natural phenomena. The beauty and grandeur of many of the phenomena occurring in the atmosphere, and the curiosity excited concerning their causes, probably contributed to interest people in them. Meteorology appears to have been first treated systematically, as distinct from astronomy and astrology, by the Greek philosopher, Aristotle, more than 2000 years ago. The word

"meteor," derived from the Greek "elevated," was applied to certain phenomena having their origin in the atmosphere. These were classified into aërial, aqueous, and luminous meteors, and were all included in the term Meteorology. In his treatise by this name Aristotle gave a more detailed account of them than any preceding or contemporary writer, and Theophrastus, his pupil, wrote two books on the winds and on the signs of rain, which have been translated into Latin and English. About the same period Aratus incorporated the current weather proverbs in his poem, *Diosemeia*. The Greek historians and poets frequently alluded to atmospheric phenomena, and their example was followed by the Romans, of whom Pliny has been quoted.

No doubt the desire to ascend into the air always possessed man, but owing to the awe with which mountains seem to have inspired the ancients, there is rarely mention in their writings of climbing mountains, or of the physiological effects which could hardly have failed to be apparent upon high summits. Citing one of the few existing narratives, Aristotle relates: "Those which ascend to the top of the mountain Olympus could not keep themselves alive without carrying with them wet sponges, by whose assistance they could respire in that air otherwise too thin for respiration." This mountain

of less than 10,000 feet was said to be so high that it never rained on its summit, where, it was supposed, the air was always still. A still higher mountain, easily accessible to the ancient world, and which we know was ascended, is Etna.

Concerning the progress of meteorology, from the time of the ancient Romans to the revival of knowledge in Europe, there is little to say except that during the middle ages meteorology, like other learning, was confined to the monasteries. Speculations were current as to the extent of the atmosphere until, in the middle of the eleventh century, Alhazen, a learned Arab, computed from the duration of twilight that the atmosphere extended nineteen leagues above the earth. The same method was applied with more precision by Tycho Brahe, Kepler, and other astronomers of the sixteenth and seventeenth centuries. The earliest weather chronicles were probably noted by monks from time to time in almanacks or missals, although when this was done first we do not know. The oldest daily chronicles of the weather extant are those kept by William Merle in Oxford from 1337 to 1344. We owe it to the late Mr. Symons, the English meteorologist and bibliophile, that this MS. and many other old records have been brought to light and published. Dr. Hellmann has done even more in Germany, and this historical research is

evidence of the growing importance of the science of meteorology.

With the advent of the age of geographical discovery it was seen that the climatic features of our globe depend chiefly upon distance from the equator, proximity to the ocean, and height above it. In the tropics especially, the luxuriant vegetation, which diminishes on mountain slopes and higher up gives place to snow, must have been visible proof of the decrease of temperature with altitude, for, as Professor Daniell remarked, mountains are a gigantic registering thermometer having for the freezing-point the line of perpetual snow. The invention of instruments for measuring temperature and barometric pressure made possible the quantitative observations that have supplied the data for deducing the laws governing the atmosphere. The oldest meteorological instrument is, no doubt, the weather or wind-vane, which had its origin before the Christian era. The next oldest is the hygrometer, or instrument for measuring moisture in the air, the form which acts by absorption dating from the middle of the fifteenth century, and the condensation hygrometer being a century younger. Next in chronological order comes the rain-gauge, which appears to have been used by Castelli, a friend of Galileo, in the year 1639. The history of that important instrument,

the thermometer, is obscure, but it is certain that Galileo in Padua used an air-thermometer in the latter part of the sixteenth century, which Rey, a French physician, filled with liquid in 1631. This thermometer, as well as other physical instruments, was perfected by members of the Accademia del Cimento at Florence. These instruments are described in *Saggi di Naturali Esperienza,* written in 1666, and translated into Latin and English. The Florentine thermometers had one fixed point, that of freezing water, and contained either spirits or mercury. In 1724 Fahrenheit, in Danzig, fixed three points on the scale of the mercurial thermometer, viz. the cold produced by ice and salammoniac which he called 0°, freezing water or 32°, and the heat of the human blood which he assumed to be 96°. This thermometric scale, having 180° between freezing and boiling water, and that of Celsius, with 100°, are the only ones in scientific use to-day. It is a remarkable fact in the history of thermometers that neither of these thermometers remained in the country where it was invented; thus the thermometer of Fahrenheit, a German, came into use exclusively in England and her colonies, while that of Celsius, a Swede, is now used on the continent of Europe except in Germany, where the thermometer of Réaumur, a French- 's still in popular use. Of the four fundamental

meteorological instruments, the barometer was the last invented. Aristotle had suspected that air had weight, but it was not demonstrated until the middle of the seventeenth century, when the old axiom "that Nature abhors a vacuum" was replaced by the rational explanation, given by Galileo and Torricelli, his pupil, why water will not rise in a suction pump more than thirty-two feet. In 1643 Torricelli executed this famous experiment: he took a glass tube, sealed at one end, and filled it with mercury, then, closing the open end with his finger, he inverted it in a basin of mercury. The mercury fell to about thirty inches, which was recognized to be the weight of a column having the area of the tube and of the height of the atmosphere. The application of the barometer was due to Blaise Pascal, who repeated at Rouen Torricelli's experiment with a much longer tube filled with water, which being thirteen times lighter than mercury, stood thirteen times higher, or thirty-two feet, in the tube. Pascal, being himself at Paris in 1648, got his brother-in-law Perier to carry a barometric tube filled with mercury to the top of the Puy de Dôme, a mountain in Auvergne rising about 3500 feet above the city of Clermont. The mercury fell in the tube with the ascent, and at the top of the mountain it stood some three inches lower than at the base, showing that the

lower layers of the atmosphere are denser than the upper. Pascal repeated the experiment on the Tower of St. Jacques in Paris, and it is interesting to note that more than two hundred years afterwards, meteorological stations were established both there and on the Puy de Dôme. It was soon perceived that not only did the level of the mercury in the tube change with height, but that it oscillated continually at the same place, and from its observed relation to the state of the weather its name "weather-glass" is derived. In 1650 the weight of the air was demonstrated in another manner by Otto von Guericke, burgomaster of Magdeburg, who by means of an air-pump of his invention performed the experiment, which Aristotle had tried unsuccessfully, of weighing a vessel full of air and the same vessel exhausted of air. He also showed the pressure of the air in all directions by the famous experiment of the Magdeburg hemispheres, which, being hollow, were placed together, and after the air was exhausted from the sphere so formed sixteen horses were unable to pull them apart. Soon afterwards Robert Boyle experimented further upon the weight and "spring of the air," as he called it, and gave the name to the barometer. Both Boyle in England and Mariotte in France discovered the law, bearing indifferently names, that the pressure of gases is propor-

tional to their density. Halley, a few years later, showed that the rate of decrease in pressure differed from the rate of increase in height, and developed formulæ for measuring heights by the barometer, which were afterwards perfected by Laplace. Knowing the heights of the barometer at a high and at a low-level station, and the mean temperature of the air lying between them, it is possible to compute accurately the difference of height of the two stations, or, conversely, given this height, the difference in barometric pressure can be calculated. By the middle of the seventeenth century the most important meteorological instruments had been invented, and not only can Italy claim to be their birthplace, but the Grand Duke Ferdinand II., whose brother Leopold founded the Accademia del Cimento, distributed the new instruments in Italy and even beyond the Alps, so that in 1654 observations several times a day were begun at a dozen stations. The observations in Florence from 1650 to 1670 were preserved and constitute the commencement of instrumental meteorology.

It was the conquest of Peru which, by leading men over the high passes of the Andes, first brought them to great heights, but although we find mention in the history of the expeditions of the so-called mountain sickness, caused by fatigue

as well as by cold and rarefied air, it does not appear that scientific observations were made. Therefore, while it must be assumed that the atmospheric conditions at considerable altitudes were familiar to travellers, yet not until the middle of the last century did Bouguer, one of three French Academicians sent to Peru on a geodetic mission, fix the height of the freezing point in various latitudes, after observing that the temperature fell below freezing at night upon the mountains near the equator. During the latter part of the century, Kirwan, an English chemist, calculated the temperature for various parallels of latitude, and in 1817 Alexander von Humboldt, after a voyage around the world, published his isothermal lines, or lines of equal temperature on the surface of the globe, by which he showed that the deviation from the normal, or calculated, temperature arose from the distribution of land and water, and from the geographical relief of the former. This work of von Humboldt formed the basis of all subsequent studies in comparative climatology. Meanwhile chemistry had kept pace with physics, and in 1774 the old theory, that air was one of the four elements from which all things originated, was rendered untenable by Priestley, who proved that oxygen gas, which he discovered, was a constituent part of air. The other constituent, nitrogen, formerly

called azote from its destructiveness to life, was discovered soon afterwards, and its proportion in the air determined by the French chemist, Lavoisier.

In 1783 man became possessed of the long-sought-for means of rising freely in the air, and he speedily availed himself of it. The first balloons, filled with heated air, were called *Montgolfières* from the inventors, the brothers Montgolfier, living in Annonay, France. After animals had been sent up attached to one, Pilâtre de Rozier ventured to ascend in the aerostatic machine, first tethered captive but then set free, and before the close of the year a balloon, filled with hydrogen gas, or "inflammable air" as it was called, carried M. Charles 9000 feet above Paris. During more than a century the balloon has been the most important agent for the exploration of the atmosphere, and yet, notwithstanding the courage and devotion to science of the early aeronauts, their ascents with unsuitable instruments furnished much discordant and erroneous data. Some of the most remarkable balloon voyages and the modern methods of sounding and dredging the atmosphere, to borrow terms from the exploration of the ocean, will be described in two future chapters.

Perhaps the chief reason for the slow progress of meteorology to the status of a science is the

variable character of its phenomena with the place of observation. In this respect it differs from astronomy, which was more easily cultivated in the restricted ancient world. Only after many years of observation at different places had contributed a foundation for climatology was it realized that man, in his relation to the atmosphere, resembled marine organisms confined to the bottom of the ocean, and that in order to discover the true conditions of the atmosphere it was necessary to observe them at considerable heights. In the last century the highest point at which physical observations had been made was the summit of Mont Blanc, less than 16,000 feet above the sea. The ascent of this mountain was first accomplished in 1787 by H. B. De Saussure and his guides with much difficulty and suffering, and the observations, abridged and rendered less accurate by the fatigue and sickness of De Saussure, were also influenced by the proximity of the mountain itself. In 1802 von Humboldt and Bonpland reached a height of about 18,000 feet in the Andes, where they made important observations. The ascent of man was rapid during the first years of the nineteenth century, for in 1804 Gay-Lussac rose in a balloon, without exertion or discomfort, to the height of 23,000 feet, and there made observations which were assumed to give the true atmospheric condi-

tions. After an active campaign the conquest of the air by balloons was temporarily abandoned, and the field was left free to the mountaineer. But to-day supremacy rests with the aeronaut, for no one has succeeded in getting higher than 24,000 feet on a mountain, while the aeronaut has exceeded this altitude by a mile without great hardship, and lately has sent his unmanned balloons twice as high as the loftiest mountains.

Plate I., headed The Exploration of the Atmosphere, represents a vertical section of the lower portion of our atmosphere. On the right is a scale of miles above the sea, and on the left is a scale of barometric pressures corresponding to the height. The right-hand half of the diagram shows the eastern hemisphere with the Himalaya mountains, the left-hand half the western hemisphere with the Andes. There are seen the heights of the different kinds of clouds, measured at Blue Hill, as described in the next chapter; the highest meteorological stations, those on Mont Blanc and El Misti in Peru; the highest permanently inhabited place, which is a monastery in Thibet; and the greatest height to which man has climbed, namely, in the Andes. The heights at which observations have been made in balloons, carrying observers, or only recording instruments, may be compared with the height attained by the Blue Hill kites, to be

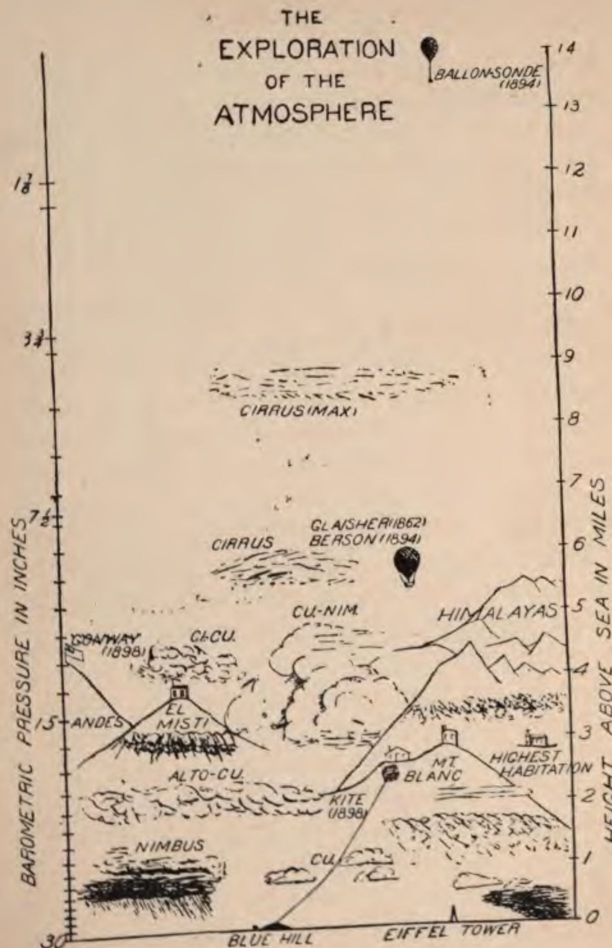

PLATE I.—COMPARATIVE ALTITUDES.

described hereafter. Other altitudes can be noted, such as the height of the snow-line on various mountains, and as a thousand-foot measure, the Eiffel Tower in Paris, the tallest structure erected by man, may be used.

The development of meteorological knowledge to the commencement of the present century has now been traced, but before beginning the consideration of the methods of exploring the atmosphere that form the subject of the book, let us, in order to understand this work better, review the general knowledge which we possess of our atmosphere as regards its origin, composition, extent, and conditions of heat and moisture. First, then, regarding the **Origin of the Atmosphere**, or vapour envelope which the name means. According to the nebular hypothesis of Laplace, our earth, like all existing suns and planets, was condensed from clouds of nebulous matter and became a highly-heated globular mass, rotating, like every celestial body, from west to east. As the earth cooled, a crust was formed, and many of the substances that now exist in the earth were suspended as clouds in the cooler atmosphere surrounding it. Eventually, these substances were condensed upon the crust; the oxygen, especially, must have been diminished by combining with the rocks, while the lighter gases, such as hydrogen, may have escaped from

the earth's atmosphere. No doubt, when vegetable and animal life began, the earth's atmosphere was denser than now and much richer in carbonic acid, which, during the carboniferous period, was absorbed by plants, and is now imprisoned in coal and limestone. Within historic times, however, there is no evidence of any change in the composition of our atmosphere, or the climatic conditions as a whole.

M. Jourdanet, a distinguished French physiologist, maintained that man appeared on the earth at the close of the tertiary period, when the barometric pressure at sea-level was, he supposed, about forty-three inches, or nearly a half more than it is to-day, and owing to the greater density of the air its temperature was also considerably higher. Under these circumstances he believed that man first occupied the high regions of Central Asia, and only emigrated to lower levels when the climatic conditions became ameliorated. In other words, M. Jourdanet believed in a literal "descent of man," but if this be true, many of the race have returned to their birthplace, for to-day millions of people dwell on the great Asiatic plateau, and on the South American Cordillera, at an average altitude of 10,000 feet, while a few live throughout the year at extreme heights of 15,000 feet.

Composition of the Atmosphere.—Dry air is a [illegible] of about one-fifth of a volume of oxygen

to four-fifths of a volume of nitrogen, besides a very small quantity ($\frac{3}{10,000}$) of carbonic acid, traces of ammonia, ozone, argon, and other recently discovered gases. The oxygen consumed, and the carbonic acid given off by animal life and by combustion, are maintained in this fixed proportion in the free air by the absorption of the carbonic acid, and the setting free of oxygen by vegetation. By diffusion and the mobility of the air, a thorough mixture is effected, with the result that the fundamental composition of our atmosphere is everywhere nearly the same. In the lower atmosphere the vapour of water is present in a varying quantity, in the average about one per cent. in weight, with a volume depending on the temperature. Dust is always suspended in the atmosphere; the coarser particles settle, but the finer ones, that come from volcanoes, may float for a long time in the high atmosphere. Dust is an important factor in the production of clouds and rain, and occasions many optical phenomena.

Extent of the Atmosphere.—If the atmosphere were incompressible and had throughout the density that it has at the earth, its height would be about five miles only, but actually it is composed of gases that follow Boyle's law and vary in volume inversely as the pressure upon them. Since the pressure decreases with height in a geometrical

progression, it would be halved for each three and a half miles of ascent were the temperature constant, but as the temperature also decreases with height, the successive intervals, beginning with three and a half miles, become shorter because the volume of a gas depends on its temperature as well as on the

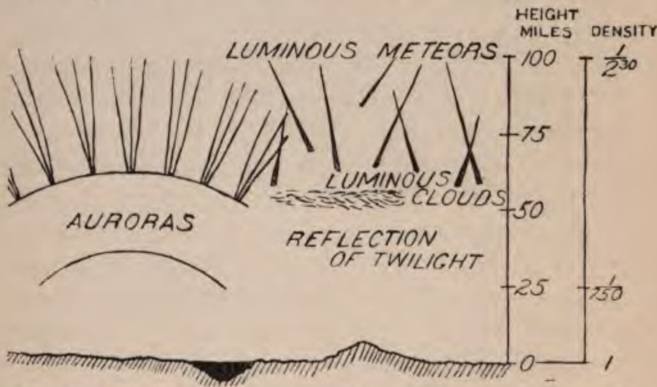

PLATE II.—OPTICAL PHENOMENA SHOWING THE HEIGHT OF THE ATMOSPHERE.

pressure upon it. The decrease of pressure with increasing height above the earth is shown by the left-hand scale of Plate I., already described, and the subsequent diminution of density to the limits of our measurable atmosphere is indicated on the right of Plate II., Optical Phenomena showing the Height of the Atmosphere. The gases composing the atmosphere probably extend to heights pro-

portional to their density; viz. oxygen to about thirty miles and nitrogen to thirty-five miles, although water-vapour nearly disappears at twelve miles. From these considerations it is supposed that the atmosphere, as measurable by the barometer, vanishes at about thirty-eight miles, and this is about the height indicated by twilight, which is the reflected light of the sun when 18° below the horizon. After the great eruption of the volcano Krakatoa in the South Seas in 1883, the brilliant sunset glows and the longer twilight showed that the dust emitted by the eruption remained for more than a year suspended at a height of at least sixty miles. The so-called "luminous clouds" seen at night during the same period, and which were probably these same dust particles still illumined by the sun, were found by trigonometrical measurements to have about the same altitude. Although it is computed that at a height of seventy miles the air has less than one-millionth of its density at sea-level—which is about the density of the air remaining in the exhausted bulb of an incandescent electric lamp—it is there sufficiently dense to render meteors luminous by friction after they with great velocity enter our atmosphere. The height of these meteors has been found, from simultaneous trigonometrical measures at two stations, sometimes to

exceed one hundred miles, and if we suppose the aurora borealis to be an electrical discharge in highly rarefied air, measures made in the same way indicate as great a height for our atmosphere. The height of the aurora varies enormously, but the average altitude of it and of the other phenomena described, with the corresponding computed density of the air, are shown in the preceding diagram, in which the depth of the ocean of air may be compared with the deepest seas and the highest mountains. While, as Professor Young says, it cannot be asserted that the atmosphere has any defined upper limit, yet the kinetic theory of gases seems to afford evidence that the molecules of oxygen and nitrogen do not escape from the earth's attraction, and therefore the hypothesis of Professor Förster is unwarranted, that interplanetary space is filled with *Himmelsluft*, or very thin air.

Temperature of the Atmosphere.—The warmth of the atmosphere is derived chiefly from the sun's rays which, arrested by the earth's surface, are partly reflected and partly radiated back through the atmosphere. Not more than seventy-five per cent.—Professor Langley says only sixty per cent.—of the heat of the sun, which is received vertically on the upper surface of the atmosphere, penetrates to the earth, and very much less than this when the

angle of the sun is low. The reason why temperature diminishes as we ascend, is partly owing to the greater loss of heat by radiation through the thinner envelope of the upper strata, and partly owing to the greater absorption of the heat given off from the earth by the lower and denser strata. In general, it may be said that there is a diminution of 1° Fahrenheit for each three hundred and thirty feet that we rise vertically, but this rate varies greatly at different heights, places, and times. For instance, the decrease is not the same on mountains as it is in the free air, and in the northern hemisphere it is greater on the south than on the north sides of mountains; it is usually greatest near the ground, and is faster in summer than in winter. But in the average, the temperature falls as much for three hundred and thirty feet of elevation as it does for a change of seventy miles on the earth's surface north or south of the equator. When dry air rises, because it is heated and thereby is made lighter, the laws of thermodynamics show that, by reason of its expansion, its temperature is decreased 1° Fahrenheit for each one hundred and eighty-three feet that it ascends, and, by compression, its temperature is increased as much if it is made to descend the same distance. This is called the "adiabatic rate of change of temperature," because it is produced by an altera-

tion in the density of the air, due to variation in pressure, without the addition or loss of heat. In the course of this book there will be occasion frequently to refer to this law of heating and cooling. The adiabatic rate of change is seldom observed on mountains because of their influence upon the currents of air in contact with their flanks, or even in balloons, on account of imperfect measurements, but, as will be explained in the closing chapter, the adiabatic change of temperature is confirmed by the observations with kites, which furnish the best method of obtaining the temperature of the free air up to moderate heights. The adiabatic cooling of rising currents of air is another reason for the rapid decrease of temperature with height up to a mile or more. The upper air alters its temperature from diurnal and seasonal causes much more slowly than the lower air, and a mile above the earth the daily change of temperature, apart from the passage of "warm and cold waves," is less than one degree. At a height of six miles above the earth a temperature much below zero constantly prevails, while, at ten miles, 80° below zero has been recorded in a balloon—this is approximately the temperature ailing winter and summer above pole and or. These facts are expressed graphic- Plate III., Temperature at Different

Latitudes and Altitudes, which represents half of a section of the earth, from the north pole to the equator, with the superincumbent atmosphere.

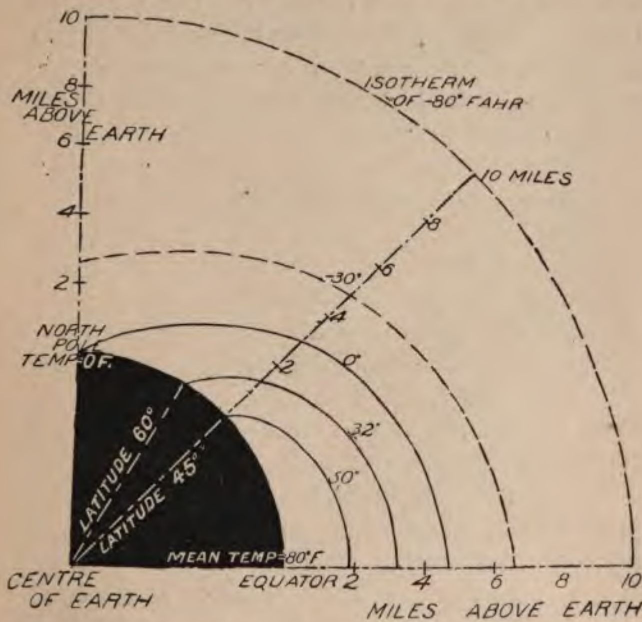

PLATE III.—TEMPERATURE AT DIFFERENT LATITUDES AND ALTITUDES.

Perhaps it should be explained, that whereas the curvature of the earth with respect to the height of the atmosphere in the previous diagram was not exaggerated, in the present diagram the height of

the atmosphere over the radius of the earth is enormously increased. At the north pole the mean annual temperature is about 0° Fahrenheit, and at the equator it is about 80°. It is seen that the atmospheric layer having a temperature of 50° (here represented in section by a line) touches the earth at 45° latitude, but is about two miles above the equator. In the same way the line of freezing (32°) leaves the earth's surface at 58° latitude and rises to about three and a half miles over the equator; the line of 0° rises from the pole to about seven miles at the equator. This is familiarly illustrated by the fact that only the highest mountains in the tropics are snow-capped, while within the arctic circle the snow-line descends nearly to sea-level. The lines in the diagram show the mean annual temperatures, but the isothermal surfaces rise in summer and sink in winter, the change of altitude being greatest in northern regions and near the ground. Frequently there is an inversion of temperature, that is to say, it is warmer above than below. Notably, in Siberia, where the winter temperature is 60° below zero, there can be no immediate decrease of temperature with height, and it is probable that there is a warmer layer of air interposed between the very cold earth and the still colder upper air, so the temperature first rises rapidly with eleva-

tion and then falls slowly to the limits of the atmosphere. In temperate latitudes it often happens, with a high barometric pressure, in winter that the mountain stations enjoy a long period of still and relatively warm weather, as compared to that experienced in the valleys. But the subject of inversions of temperature will be discussed at length in considering the results of the balloon and kite observations.

The observations from balloons at great heights are neither sufficiently numerous nor accurate to enable us to form an opinion as to what is the temperature of interplanetary space, which the kinetic theory of gases places at 460° Fahrenheit below zero. This temperature is called "the absolute zero," and is calculated from the fact that air under a constant pressure contracts $\frac{1}{490}$ of its volume for each degree Fahrenheit it is cooled below the temperature of freezing water, and consequently under no pressure it should have an infinite volume and a temperature of about 490° below freezing, or 458° below zero. There are other hypotheses regarding the temperature of space, but since it can never be measured directly, it will probably remain a matter of speculation. It is certain, however, that if the earth were deprived of its atmosphere, the temperature would fall very low, and even with our atmosphere as a

blanket our earth would be uninhabitable were it not for the aqueous vapour which controls the selective absorption of the solar rays, transforming them into obscure rays so that they cannot escape from the atmosphere. Water-vapour, then, is a very important factor in the physics of the atmosphere, but it can only be considered briefly here.

Moisture of the Atmosphere.—The air is constantly absorbing moisture from the water on the earth, but the tension of this aqueous vapour decreases with elevation much faster than does the atmospheric pressure. At the height of about a mile and a quarter half the quantity of water-vapour is below, while we must rise about three and a half miles to reduce the quantity of air one-half, as may be seen in Plate I. The relative humidity, or the percentage of moisture in the air, as compared to the amount which it could contain at that temperature, is nearly the reverse at low and at high levels. It is found from the kite-observations at Blue Hill, that up to the height of a mile or two the air is drier during winter and at night, and damper during summer and in the day-time than it is near the ground. At great heights probably the air is always very dry. The condensation of the invisible vapour into a visible form sidered in the next chapter on clouds.

apparent that our observational knowledge

of the atmosphere is gained by two general methods of exploring it, viz. observations made from the earth upon clouds and optical phenomena at a distance, and observations made directly in the air itself. Although it was realized at the beginning of this century that meteorological observations were almost all conducted at the very bottom of our atmosphere—"in the shoals and shallows of the ocean of air," von Humboldt said—yet only within the past thirty years was it thought necessary to replace the occasional observations on mountains by systematic and long-continued ones, comparable to those so generally carried on at low levels. It is an evidence of the zeal in America to advance the young science of meteorology, that the first mountain-top station in the world was established in 1871 upon Mount Washington, and that both this exposed post of observation, 6300 feet above the sea, and the one more than twice as high on Pike's Peak, which was for a long time the highest in the world, were maintained for many years by the United States Signal Service. The present highest station in the world is maintained by the Harvard Observatory upon El Misti in Peru, where, at a height exceeding 19,000 feet, a combination of self-recording instruments was constructed by my assistant, Mr. Fergusson, to operate during three months without

attention. It must be admitted, however, that the addition to our knowledge of the physics of the atmosphere afforded by the American stations has been slight and incommensurate with the expense incurred. More has been gained from the mountain stations in Europe, notably from those in the Austrian Alps, which have furnished data for Dr. Hann's splendid discussions of the thermo-dynamics of the atmosphere. While mountain stations present the only means of obtaining continuous observations at a considerable and constant height, still they have serious drawbacks. Not only is the distribution of mountains over our globe irregular, but since they form part of the earth's crust, terrestrial influences affect all observations made upon them. In the case of plateaux this was at once admitted, but by placing the stations on the summits of high and isolated peaks, it was hoped to approximate to the conditions of the free air. It is now recognized that the equilibrium of the atmosphere is so delicate that for its dynamical study exact and minute measurements of temperature, moisture, and currents are required, and the methods which will be described are intended to give the values of these elements free from terrestrial disturbances.

Clouds, balloons, and kites naturally supplement another. While clouds indicate the direction

and velocity of the air at different heights, yet the lower clouds often conceal the upper strata, or there may be no clouds at all, in which case balloons or kites will aid us to determine the drift of the currents. When there is little wind at the ground, or to reach heights of several miles, we must employ balloons, but otherwise kites are preferable in most cases. The thermal and hygrometric conditions of the free air can be ascertained only by personal observations in balloons, or by raising self-recording instruments with balloons and kites, and this latter method it is predicted will be the path of greatest progress.

cumulo-nimbus, as they are called. The lower limit of the cloud region is determined therefore by the height at which the rising currents reach their dew-point, and the altitude of the cloud formation depends upon the humidity of the ascending current, the drier it is, so much the higher must it rise to have its vapour condensed. In storms the rising current mingles with the stronger horizontal current above, which carries with it the upper portion of the cloud, and covers the whole sky with a uniform sheet. The wave, or ripple cloud, has been explained by von Helmholtz and von Bezold to be due to the undulations in a horizontal current producing alternate rarefaction and condensation of its water-vapour through changes of temperature. Still another cause of low-lying clouds is the cooling of the air to its dew-point by contact with a cold surface, such as the earth when cooled by radiation during a clear night, or the polar currents of the ocean. Fog is often formed in this way, which we call stratus cloud when it rises above us. The highest clouds consist of ice crystals, because the temperature of the air where they are is much below that of freezing water. Although it is possible to cool drops of water considerably below 32° Fahrenheit without congelation, yet it can be told with certainty that the clouds are composed of ice if the sun and moon when seen through them are

surrounded by the large rings or halos, which the theory of optics shows can only result from refraction of light by ice crystals, whereas water drops in the clouds produce the smaller coloured rings, which are called coronæ. The old question, why clouds float unless their particles are hollow, is easily answered, for they do not float, and always tend to sink if they are not supported by the currents of air. In sinking into warmer air the particles are vapourized and become invisible, but others rising are condensed and take their places, so that the cloud persists, although its particles change. This is illustrated by the "cloud banners," which frequently stream from mountain peaks, and are caused by the rise of air up the mountain side. Even in a strong wind the cloud remains attached to the peak, showing that its particles are being renewed continually; but if, as is often the case, the wind descends on the leeward side of the mountain, the cloud particles disappear.

Lamarck, the celebrated naturalist, in the opening year of the present century, first proposed a classification of cloud forms. Two years later Luke Howard, a London merchant, published his epoch-making essay on *The Modifications of Clouds*. The theories there advanced and the nomenclature proposed have been accepted generally to our day, notwithstanding the more complete classifications

devised by Poëy, Ley, and others. Howard believed that clouds are formed by the aqueous vapour which rises from the earth, and that the globules which compose them are solid, and are not filled with hydrogen gas as had been maintained by Deluc and De Saussure. Howard classified the clouds as we do to-day, according to their appearance, into three principal types, viz. stratus, cumulus, and cirrus, which represented also low, middle, and high clouds. Stratus is the sheet of low-lying cloud which forms at night, and commonly rests on the earth; cumulus is the heaped-up cloud of the day-time; and cirrus is the curl cloud of the high atmosphere. These three types were further divided into four intermediate types, viz. nimbus, cumulo-stratus, cirro-stratus, and cirro-cumulus. Howard's nomenclature was used almost exclusively, until in 1889 the International Meteorological Conference that met at Paris recommended the adoption of another classification, based on Howard's, but modified by two experts, Abercromby of England and Hildebrandsson of Sweden. This classification also disregarded the origin of clouds, and was based only on their appearance. The next year an atlas, with coloured pictures of the clouds, separated according to the new nomenclature, with descriptive text, was prepared by Dr. ""'debrandsson, assisted by Drs. Neumayer and

Köppen of the Deutsche Seewarte, or German National Meteorological Observatory. This atlas was adopted by the principal meteorological institutions on the continent of Europe for their observers. The preface contained the following statement: "The study of the forms of clouds is daily increasing in importance, both from the standpoints of theory and of weather prediction. Observations taken at the bottom of the atmospheric ocean are plainly insufficient to determine its circulation. The clouds, however, furnish information about the condition and motion of the air at various levels. But, a comparison of the observations of different observers is only possible when the same ideas are connected with the same expressions. It is hardly possible to give a sufficient verbal description of such indeterminate and changeable forms as those of the clouds; graphical representations are therefore necessary, with the help of a short description, in order to enable an observer to connect what he sees in the sky with what he finds in the instructions. In order that a cloud picture may be intelligible to non-specialists, the clouds and the blue sky must, at least, be plainly distinguishable from each other."

The meeting of the directors of the meteorological institutions in different parts of the world,

which was held at Munich in 1891, decided to adopt the classification of Abercromby and Hildebrandsson, and a committee was appointed to prepare an Atlas of Clouds, which should be cheaper than the preceding one. This committee, of which the writer has the honour to be the American member, met at Upsala in 1894. It defined the various forms of clouds, selected typical pictures to illustrate them, and drew up instructions for observing. This atlas, which was published in 1896, is the recognized authority on cloud forms.

Meanwhile the United States Weather Bureau had issued a plate of clouds, printed in one colour, to familiarize its observers with the new system. The Navy Department has also an interest in clouds, for several thousand seamen in various parts of the world send their special logs to the United States Hydrographic Office. The Hydrographer, a few years ago, was Captain Sigsbee, who, long before he became known to the public as commander of the ill-fated *Maine*, had achieved scientific reputation from his investigations upon the depths and the currents of the ocean. Captain Sigsbee desired to render comparable the observations of clouds which were being made all over the world, and to this end he resolved to publish a coloured atlas of the international cloud types which should be intelligible to seamen, and yet

not too costly for his office to supply. After two years of experimenting, during which the writer and his assistant, Mr. Clayton, were frequently consulted, the *Illustrative Cloud Forms*, with and without descriptive text, were issued in 1897 by the Hydrographic Office, and in several respects this atlas is the best. Still, it is impossible for anything but a photograph from the cloud itself to show the extreme delicacy of certain forms. Perhaps it should be explained, however, that as the blue sky and the white clouds act with almost equal actinic effect upon the sensitized plate, in order to obtain the proper contrast between sky and cloud it is necessary either to polarize the light from the sky, or, as is most commonly done, to separate the coloured rays by allowing them to pass through a yellow screen, and to fall upon autochromatic plates.

Before defining the ten principal types of cloud it should be explained that two general classes of clouds are distinguished, separate or globular masses, which are most frequently seen in dry weather, and forms which are widely extended or completely cover the sky, which are typical of wet weather. Both these classes of clouds are found at all heights.

Cirrus are thin, fibrous, detached, and feather-like clouds formed of ice-crystals. They are the

highest of all the clouds, and move with the greatest velocity.

Cirro-stratus form a thin whitish veil, more or less fibrous, which often produces halos around the sun and moon and other optical phenomena.

Cirro-cumulus are flocks of small detached fleecy clouds, generally white and without shadows.

Alto-stratus is a grey or bluish veil through which the sun and moon are faintly visible, occasionally giving rise to coronæ. Its altitude is only about half that of Cirro-stratus.

Alto-cumulus are flocks of larger, more or less rounded, white or partially shaded masses, often touching one another, and frequently arranged in lines in one or more directions.

Strato-cumulus are large globular masses or rolls of dark cloud, frequently covering the whole sky, especially in winter.

Cumulus are piled clouds with conical or hemispherical tops and flat bases. They are formed by rising currents of heated air, and are therefore most common in summer and in tropical regions. When broken up by strong winds the detached portions are called Fracto-cumulus.

Cumulo-nimbus is the massive thunder shower cloud rising in the form of mountains or turrets, and generally having above a screen of fibrous appearance (False Cirrus), and underneath a mass

of cloud similar to Nimbus from which rain falls.

Nimbus is a dense, dark sheet of ragged cloud from which continued rain or snow generally falls. Broken clouds underneath, forming the scud of the sailors, are called Fracto-nimbus.

Stratus is a thin uniform layer of cloud at a very low level. When the sheet is broken up into irregular shreds it is called Fracto-stratus.

Having described the origin and appearance of the different clouds, an account will now be given of the measurements made at Blue Hill Observatory and the information which they give about the circulation of the atmosphere. The work there was taken up in 1887 in consequence of the interest of the meteorologist, Mr. Clayton, in the study of clouds; his discussion of the cloud observations, published two years ago with the Blue Hill observations, has been termed by far the most thorough study of the kind ever undertaken in America if not in the world. Most of the conclusions which are stated popularly here have their scientific expression in his work.

The first investigation related to the amount of cloud at different hours of the day, and during the various seasons. It is customary to note the degree of cloudiness on a scale of from 0, when there are no clouds, to 10, when the whole sky

is covered. For twelve years the amount of cloud at each hour of the day has been recorded at Blue Hill. The personal observations have been supplemented during the day-time by an automatic instrument called a sunshine-recorder, for it has been proved that the cloudiness is very nearly the inverse of the bright sunshine. Consequently, if, as is usual there, the sun shines forty-six per cent. of the time when it is above the horizon, the cloudiness is very nearly fifty-four per cent., which is the average for the year. The instrument generally used for this purpose is a glass sphere which acts as a burning-glass, and chars a strip of cardboard placed concentrically around the lower part of the sphere. As the sun moves, the image on the card moves in the opposite direction over the card, burning a line as long as it shines, but leaving the card untouched when it is cloudy. In a similar way a record may be obtained on sensitized "blue paper" by allowing the sun's rays to enter a dark chamber containing the paper. The maintenance of personal observations at each hour of the night is arduous, and, therefore, during ten years an automatic instrument has been used at Blue Hill which deserves to be better known. It is called the pole-star recorder, and was devised by Professor Pickering, director of the Harvard College Observatory. The instrument is very simple,

and consists of a telescopic camera focussed on Polaris. This star is not at the north pole of the heavens but a little more than a degree distant, and, consequently, it describes a small circle in the heavens during twenty-four hours. When the sky is clear around Polaris its trail upon the photographic plate is continuous, but when the sky is partly or entirely covered with clouds the trail is broken or obscured. Of course the plate is not exposed until after dark, and a shutter is closed by a clock before dawn. The only hourly records of cloudiness at night in the United States are obtained by this instrument on Blue Hill and at Cambridge. It will be objected, perhaps, that the cloudiness derived from observations of the sun or the pole-star is not the amount over the whole sky, but only that in the region of the luminary. This is true, but it is found that the average of the records for a month or a year agrees very closely with the average of estimates of cloudiness over the whole sky during these periods. The use of the pole-star is preferable to that of the sun, because in our latitude it gives values at a point about half-way between the horizon and the zenith; while since the sun travels at a variable height across the sky, when its altitude is low the same mass of cloud may intercept more sunlight than when it shines vertically. From ten years' observations the

following deductions have been made concerning the variation in the amount of cloud at Blue Hill. For all the months the diurnal amount of cloud is greatest about one o'clock in the afternoon, on account of the frequency of cumulus clouds near the warmest part of the day, while the next greatest amount, due to the frequency of stratus clouds, occurs near sunrise, or at the coldest time of day. All over the world the least cloudiness is in the evening, when the sum of the combined effects of radiation and isolation is least. The annual period in the cloudiness is complex, because the amount of cloud is connected with changes of humidity at many different levels in the atmosphere, but in the northern hemisphere there is most cloud during the first half of the year and least during the latter half, probably because the increasing warmth at the earth's surface produces increased ascending currents until summer, while the chilling of the earth's surface in the autumn becomes unfavourable for ascending currents. The distribution of cloud over the globe is intimately connected with the general atmospheric circulation, being greater where there are rising currents and less where there are downward currents. The reason, naturally, is that as descending air becomes warmer and therefore relatively drier, the clouds in it evaporate and disappear. A cloudy belt

encircles the earth at the equator, and on either side are two belts of less cloud, but in higher latitudes the cloudiness increases. If we could see our earth from outside its atmosphere, the light reflected from the upper surfaces of the cloud-belts would probably make them appear bright. From the markings on a planet that are known to be caused by condensation, a French meteorologist, M. Teisserenc de Bort, believes that the circulation of its atmosphere can be inferred, for wherever on the surface of the planet bright spots are seen, there the vapour of rising currents should be condensed. If this be true, there is a resemblance between Jupiter, as we see it, and the earth as it would appear from another planet, the bright bands being cloud surfaces, and the dark patches glimpses of the surface of the planet beneath.

Observations of the direction of motion, and apparent velocity of clouds at different heights, have been made at Blue Hill several times a day since 1886. To measure the motion of clouds the nephoscope (Fig. 1) is used. It consists of a horizontal circular mirror with a concentric circle of azimuths and an eye-piece *C*, movable in a plane *BD* at right angles to the mirror and also around it, through which the image of the cloud is brought to the centre of the mirror *A*. It can be proved by geometry that the motion of the cloud-image is

proportional to the movement of the cloud itself, so by noting in what direction and how far the image is displaced in a given time, we have the true direction of motion of the cloud itself and also its relative velocity, comparable with the velocity of all clouds having the same height. If

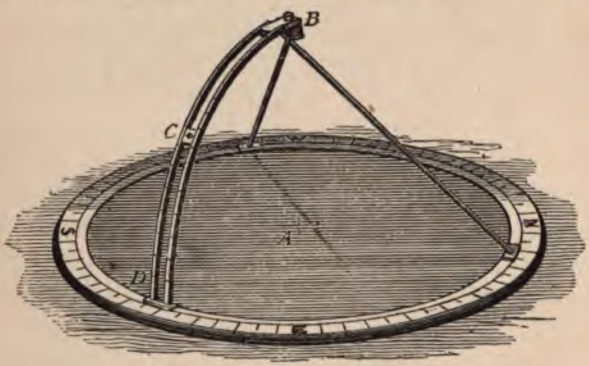

Fig. 1.—Nephoscope at Blue Hill Observatory.

the height is known, then the relative velocity can be easily converted into absolute velocity, and thus the velocity of currents at different heights in the atmosphere is accurately ascertained.

The height of clouds seems to have been measured trigonometrically from two stations as early as 1644 by Riccioli and Grimaldi, two Jesuits of Bologna, but notwithstanding these measure- ; and some conclusions derived from observa-

tions on mountains, and in balloons, the altitudes of the different clouds were not known with any accuracy until in 1884 Ekholm and Hagström made a series of trigonometrical measurements upon the different kinds of clouds at Upsala, Sweden. About the same time attempts were made at Kew Observatory to measure clouds by photography, and in 1885 probably the first trigonometrical measurements in America were made at Cambridge, Mass., by Professor W. M. Davis and Mr. A. McAdie. In 1890–91 the Swedish methods were employed at Blue Hill by Messrs. Clayton and Fergusson of the Observatory staff, and until recently the measurements there and at Upsala comprised all that was known accurately about the heights and velocities of the various species of clouds.

The trigonometrical measurements at Blue Hill were made as follows: at two stations, one at the Observatory, the other at the base of the hill about a mile distant, two observers determined simultaneously the angular altitude and azimuth of some point on the cloud which was agreed upon by telephonic conversation. If, as is generally the case, the lines of sight did not meet, the trigonometrical formulæ gave the height of a point midway between the crossing of these lines. Such was the accuracy of these measurements that the probable

error of the calculated heights of the highest clouds is only a few hundred feet. Successive observations at the two stations of the position of the cloud enabled its velocity to be calculated, or, as already explained, this may be got from the relative

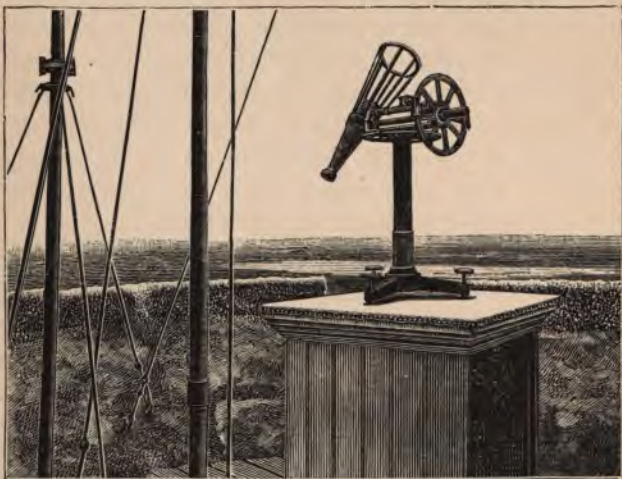

FIG. 2.—Cloud Theodolite at Blue Hill Observatory.

velocity measured at one station, if the height of the cloud be known. Fig. 2 shows the theodolite on the tower of the Observatory. Five other methods of measuring clouds have been employed at Blue Hill: (1) The only method of finding the height of lofty and uniform cloud strata is by

means of the light thrown on them from below, and on Blue Hill the electrical illumination of the surrounding towns is utilized. The angle which the centre of the illumination makes with the horizon is measured, and knowing the distance of the town, the right-angled triangle may be solved. (2) An accurate method for low and uniform clouds is to send kites into them, as will be explained in the closing chapter. (3) When the clouds are low enough to cast shadows on the ground, the angles of the cloud and sun as seen from the Observatory are measured, and with the distance of the shadow from the hill-top, ascertained by a map, this triangle can be solved. The times of passage of the shadow over known points on the landscape afford another means of calculating its velocity. (4) A method that was suggested by Espy, the pioneer American meteorologist, for getting the altitude of the bases of clouds lying within a mile of the earth, is to find the difference in temperature between the air and the dew-point at the ground, and to compute the height at which this difference should disappear. When the temperature of the rising currents increases, as on warm days, and the level of the dew-point rises higher, the cloud can be seen to ascend, and, in fact, the measurements at Blue Hill show that the clouds of moderate altitude are highest during the

warmest part of the day. (5) Finally, very low stratus or nimbus may be measured by noting the heights of their bases on the sides of the hill.

The identity of cloud-forms all over the world has been established, and as a result of the measurements at Blue Hill, the heights and speed of all clouds observed there are known. The averages have been plotted in the five levels into which we separate the clouds in Plate IV., Heights and Velocities of Clouds, where ordinates represent heights and abscissæ velocities, and, consequently, the distances of the various forms of clouds above the horizontal base indicate their heights, and the distances from the left-hand vertical line their velocities. For comparison, the velocity of the wind on Blue Hill, a few hundred feet above the general level of the country, is represented. The mean height of the cirrus is about 29,000 feet, but this cloud sometimes reaches 49,000 feet. The mean height of the cumulus is about a mile, but the tops of the cumulo-nimbus, or thunder-shower cloud, sometimes penetrate into the cirrus level. Generally the base of the nimbus, or rain cloud, is only 2300 feet above the ground, and it frequently sinks below the top of Blue Hill, which is only 630 feet above the sea. The poetic saying, that "Earth wraps her garment closer about her in winter," has

a scientific basis, for the average height of all the clouds is greatest in summer and least in winter. But the reverse is true of their velocity, for the

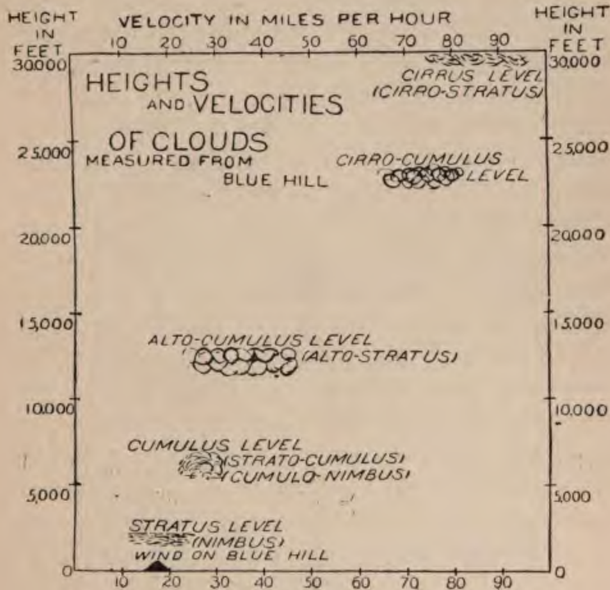

PLATE IV.

entire atmosphere moves twice as fast in winter as it does in summer, and at the lower levels the seasonal change is even greater. The average velocity of cirriform clouds is ninety miles an hour

in winter, and sixty miles in summer, but occasionally in winter cirrus have been found to have the enormous velocity of two hundred and thirty miles an hour. In the average, the velocity of the currents increases, from the lowest to the highest clouds, at the rate of about three miles an hour for each 1000 feet of height, but near the ground the increase with height is faster. It has been found that the velocity of the lower clouds is less than the velocity of the wind on a mountain of the same height, which may, perhaps, be explained on the supposition that the mountain acts like a dam to accelerate the flow of air over it. The measurements in Sweden showed that the middle and upper levels of clouds are higher than in America, but that they move less rapidly. This may be because the surfaces of equal temperature in the air are higher in the United States than in Sweden, on account of the direction of the upper currents, while the greater velocity of our high clouds corresponds with the more rapid movement of areas of low and high barometric pressure over the United States.

These results are suggestive. For instance, the energy of the upper half of the mass of the atmosphere, or that portion which lies above 18,000 feet, has been calculated to possess six times the energy of the lower half in which we live, and

as yet, none of this enormous store of energy is applied to the use of man. While it appears certain that no navigable balloon or flying machine will ever be able to stem the enormous velocity of the upper atmosphere, rarified though it is, perhaps in the future aërial machines will take advantage of the prevailing currents of the high atmosphere, as our sailing ships do of the trade winds. The observations of cirrus clouds in various parts of the world show that they always move from a general westerly direction, while below this primary drift toward the east occur the relatively permanent or transient differences of pressure which cause the deviations from the normal circulation of the atmosphere, and give rise to the local circulation in storms. In the familiar daily weather map it will be noticed that there is usually some portion marked "low," and another portion marked "high." The former is an area of low barometric pressure, into which the winds at the ground blow spirally oppos inward in the direction that the clock hands turn; the latter is an area of high barometer, out of which the winds at the ground blow in the contrary way. The former when well developed are called "cyclones," and are usually accompanied by stormy weather, and the latter, called "anti-cyclones," bring fair weather. From the observations of the directions from which the clouds move in cyclones and

anti-cyclones, we have found that above the cumulus level (at the height of about a mile) the inward inclination of the wind in a cyclone, and the outward inclination in an anti-cyclone, both disappear, and the general drift from the west prevails. The results of the observations are shown in Plate V., Atmospheric Circulation in Cyclones and Anti-cyclones, representing sections of the atmosphere, concentric to the earth's surface, in the five cloud-levels seen from above. The arrows fly with the wind and are proportional in length to its velocity, the dotted arrows indicating the probable flow of the air through the cyclones and anti-cyclones that are indicated by the circles, their axes being assumed to be nearly perpendicular to the earth's surface. Above the cumulus it will be observed that the wind in the cyclone tends to come from the south-west in front and from the north-west in the rear, while in the anti-cyclone the contrary is the case, indicating a deflection of the westerly upper current to the right in cyclones and to the left in anti-cyclones. This sustains the theory that the cyclonic circulation is struggling against a general atmospheric drift from the west which increases with altitude, and above the height of a mile becomes greater than the cyclonic influence. Higher than this, the atmospheric circulation is controlled

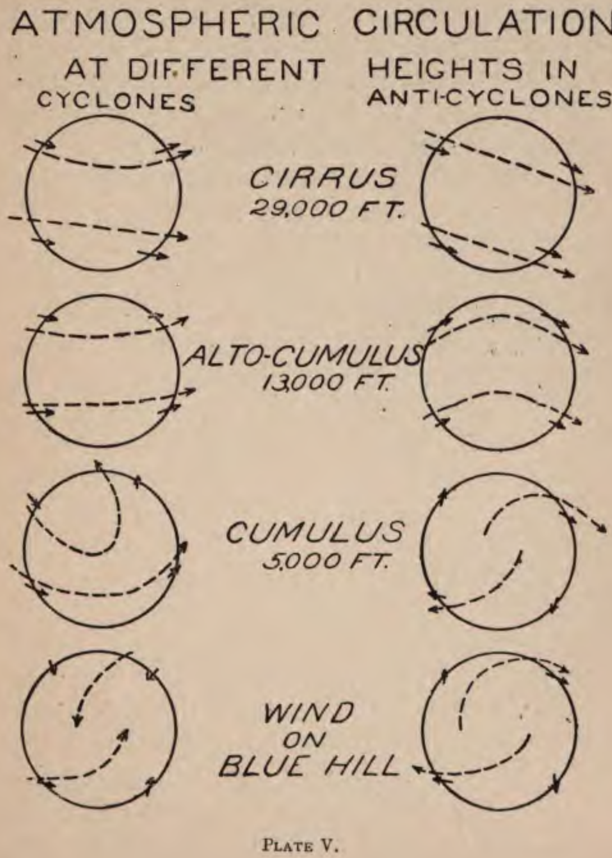
ATMOSPHERIC CIRCULATION
AT DIFFERENT HEIGHTS IN
CYCLONES
ANTI-CYCLONES
CIRRUS
29,000 FT.
ALTO-CUMULUS
13,000 FT.
CUMULUS
5,000 FT.
WIND
ON
BLUE HILL

PLATE V.

primarily by the permanent temperature gradient between equator and pole, by the seasonal temperature gradient between ocean and continent, and, in the United States, by the passage of "warm and cold waves." Mr. Clayton's investigations indicate that the motion of the upper clouds is nearly parallel to the lines of equal temperature at the earth's surface. A high temperature, by expanding the air upward, causes in the upper air a high pressure; and a low temperature, by contracting the air towards the ground, causes in the upper air a low pressure, so that the lines of equal pressure in the upper air are parallel to the lower lines of equal temperature, and since there is little friction in the upper air the motion of the wind is nearly parallel to the lines of equal pressure. Below the cumulus level the winds follow the normal cyclonic and anti-cyclonic circulation. There are two theories of the origin of these areas of high and low pressure, the "driven theory" which supposes that they derive their energy and drift from the general atmospheric movement from west to east, and the "convectional theory" which attributes their formation and progression to the difference of temperature between them and the adjacent air. While the observations on mountains have favoured the driven theory, yet the inward spiral motion of the cirrus clouds above the

anti-cyclone, indicating a lower pressure than in the surrounding air, contradicts the hypothesis, and the recent observations with kites at Blue Hill strongly support the convectional theory of cyclones.

The relation of the clouds to weather forecasting has been investigated at Blue Hill. For instance, it is found, in this region at least, and contrary to the general opinion, that cirrus clouds do not indicate rain, but do foretell a change of temperature that is proportional to the rapidity of motion of the clouds. Alto-cumulus is followed by rain within twenty-four hours three times in four. Rain follows the appearance of all high and intermediate clouds most frequently when the cloud banks are densest toward some westerly point and when they come from the west. Mr. Sweetland, an assistant, has studied special forms of cloud in their relation to the succeeding weather. He concludes that cirrus plumes precede fair weather, while dense clots of cirro-cumulus are followed by rain. Rounded pendants, or mammillated clouds, in the lower levels indicate rain, but in the upper levels fair weather. Of all the forms, the dark sheet of stratus, and clouds of lenticular shape, are most frequently followed by rain. Of clouds presaging changes in temperature, the turreted cumulus, which is connected with thunder-

storms, precedes the greatest fall in temperature, and next in order come lenticular clouds, flaky cirrus, and alto-cumulus. In general, flat and flaky clouds, clouds forming and disappearing rapidly, and clouds changing to forms at a higher level precede dry and cooler weather.

It will be seen that this modern study of clouds as prognostics simply adds to the weather proverbs that have come down to us from the time of Theophrastus. It does not appear, however, that cloud forms alone can usually serve to predict rain for more than twenty-four hours, but for a few hours in advance the appearance of certain cloud forms frequently furnishes the observer more trustworthy signs of coming rain than does the synoptic weather map. To a forecaster in possession of telegraphic data, the prevalence of rapidly-moving cirrus over a wide area indicates a rapid storm movement, with sudden and marked changes of weather and of temperature, while slowly-moving cirrus indicate slight changes of temperature and dry weather. The direction of the cirrus movements in front and around a storm centre will usually point out the future movement of the storm, which tends to advance in the same general direction.

The work done at Blue Hill shows the importance of cloud observations to elucidate the general

movements of the atmosphere, as well as the circulation of the air above barometric maxima and minima, which can result practically in making accurate weather forecasts possible a day or two in advance. The systematic observation of the upper currents was brought to the attention of the International Meteorological Committee by Dr. Hildebrandsson in 1885, and at the meeting of the International Cloud Committee in 1894, besides the adoption of the nomenclature of clouds and instructions for observing them, it was decided that observations of their motion, as well as measurements of their height, should be made in various parts of the world. Accordingly, the year commencing May 1, 1896, was designated as the "International Cloud-Year," and observations with nephoscopes of the direction of motion and relative velocity of clouds were begun at many stations in Europe and Asia, and at fifteen stations in the United States. Trigonometrical measures of the heights of clouds were undertaken at stations in Norway and Sweden, Russia, Finland, Prussia, and France, as well as at Toronto, Manila, and Batavia; in the United States the measurements already described were recommenced at Blue Hill, and the Weather Bureau equipped a similar station in Washington. In Europe it is thought that the determination of heights by photogrammeters, as

the theodolites with attached photographic cameras are called, possesses advantages over the visual theodolites, and it is true that not only is the kind of cloud recorded on the plates, but there are available for calculation as many points on the cloud as can be identified on the two plates exposed simultaneously at both stations. On the other hand, in the case of nearly uniform or dark cloud-strata, it is easier to see points for measurement on the cloud than to fix them on the photographic plates. For this reason, and from the difficulty of manipulating the photogrammeter, visual instruments were adopted both at Blue Hill and at Washington. The work was successfully carried on until May 1, 1897, and the observations and measurements were reduced at Blue Hill according to the plan prescribed by the Committee. Already the observations and measurements made at Upsala, Manila, and Blue Hill are published, and the others will follow. The discussion of the correlated data from the various countries will probably increase our knowledge of the circulation of the atmosphere, which is certainly one of the most interesting and important questions in the physics of the globe. The result will have been reached by international co-operation, of which the benefits to science are everywhere manifest to-day. But for the whole problem to be solved, it is necessary, not only to

know the movement of the air, but, as far as possible, to ascertain its conditions of heat and moisture. This may be accomplished by the use of balloons and kites, to be described in the remaining chapters.

CHAPTER III

BALLOONS—NOTABLE ASCENTS AND RESULTS OBTAINED —CAPTIVE BALLOONS

IN the first chapter the invention of the hot-air and the hydrogen balloon was chronicled, and it was stated that on December 1, 1783, Charles rose from Paris to a height of 9000 feet. Public interest in France was greatly excited by this wonderful extension of the realm of man, and numerous ascensions with *Montgolfières* and *Charlières*, as the hot-air and hydrogen balloons were respectively called, took place in Paris and the provinces. The uses of the balloon seemed innumerable, and Lavoisier was instructed by the Academy of Sciences to draw up a report on the value of the new discovery. After having described in detail the ascensions which he had witnessed, the great chemist stopped, appalled at the multitude of problems which the balloon could solve. History has shown, however, that no commercial application of the balloon was possible, and that

aside from its spectacular attractions, its chief use has been for scientific observations.

The first persons in England who devoted themselves to aërial navigation were foreigners. Two of them were Italians, the philosopher Tiberius Cavallo, who already in 1782 had showed to a London assembly that soap-bubbles filled with hydrogen will rise, and therefore had almost anticipated the invention of the hydrogen balloon, and the diplomatist Vincent Lunardi, who made some daring balloon ascents in 1784. But the honour of making the first scientific balloon voyage is due to a Bostonian, Dr. John Jeffries. Dr. Jeffries graduated at Harvard College in 1763 and then practised medicine in England, where he became a loyalist, and during the Revolution was with the British troops. In London he interested himself in aerostation, and, aided by the Royal Society, ascended in a balloon because, he said, "I wished to see the following points more clearly determined: first, the power of ascending or descending at pleasure, while suspended and floating in the air; secondly, the effect which oars or wings might be made to produce towards the purpose and in directing the course of the balloon; thirdly, the state and temperature of the atmosphere at different heights from the earth; and fourthly, by observing the varying course of the currents of

air, or winds, at certain elevations, to throw some new light on the theory of winds in general." A French professional aeronaut named Blanchard had made three ascents in France and one in England, and Dr. Jeffries paid one hundred guineas to accompany Blanchard on his fifth ascent, which was made from London November 30, 1784. He took with him a thermometer, a barometer, a hygrometer, an electrometer, and a mariner's compass, also several numbered bottles, filled with water and provided with glass stoppers, which were to be emptied and corked up at different heights in the atmosphere. It was arranged to record the observations on ruled paper with a silver pen, because the doctor would not trust a common pen or pencil as liable to accident. He also had a map of England to determine the direction which the balloon took. Jeffries' English sentiments are shown by this quotation from his narrative: "I had provided a handsome British flag, invidiously represented the next day in one of the public papers to have been the flag of the American States." The barometer and thermometer were observed every few minutes, and the hygrometer occasionally. The electrometer did not change its indications. Samples of air were obtained and sent to the Royal Society, but it does not appear that they were ever analyzed. The balloon rose nearly

two miles, and descended safely in Kent after an hour and a half. Jeffries' observations compare favourably with those made until recently; indeed, for nearly a century there was little improvement in the apparatus. The decrease of temperature which Jeffries found, viz. 1° for 360 feet rise, and the decreasing humidity with height agree very well with later observations.

Jeffries and Blanchard undertook a more perilous voyage on January 7, 1785, from Dover across the Channel, landing in the province of Artois, after, so runs the announcement, "we were suspended and floating in the atmosphere two hours over the sea and forty-seven minutes over the land of France." The voyagers were cordially welcomed, and were entertained lavishly in Paris as being, Jeffries says, "the first who passed across the sea from England into France by the route of the air." No instruments but a barometer and a compass were carried, and the only scientific result worthy of notice was that the balloon seemed to lose buoyancy over the sea, due to what Jeffries thought might be "the power of attraction over the water." The height of the balloon was measured trigonometrically by French officers in Calais, who found by angular measures, when the balloon was midway across the Channel, that its height was 4500 feet. Jeffries' voyages have been described somewhat at length because

the first scientific balloon voyage is generally attributed to the Belgian physicist, Robertson, who ascended from Hamburg in 1803 to the improbable height of 24,000 feet. Robertson made his third ascent the next year from St. Petersburg, accompanied by the Academician Sacharoff. This was a scientific voyage, instituted at the request of the Russian Academy, to ascertain the physical state of the atmosphere and the component parts of it at different heights, also the difference between the results of vertical ascents and the observations of Deluc, De Saussure, von Humboldt and others on mountains, which it was rightly concluded could not be so free from terrestrial influences as those made in the open air. Among the experiments which the Academy proposed were the following: change of rate of evaporation of fluids, decrease or increase in the magnetic force, inclination of the magnetic needle, increase of heat of the solar rays, fainter colours in the spectrum, influence of rarefaction of the air on the human body, as well as some other chemical and philosophical experiments. A height of about two miles was reached, and many interesting observations were made, but since the instruments were not easily used in the basket of the balloon, the results were unsatisfactory and required repetition to be conclusive.

The Academy of Sciences of Paris now took up

the investigation with the special object of proving whether the magnetic force decreased as Robertson in a balloon and De Saussure in the Alps had supposed. Two young physicists, Biot and Gay-Lussac, were chosen to carry out the investigations. They ascended from Paris on August 24, 1804, provided with all necessary instruments, but the balloon was too small to rise higher than 13,000 feet. Gay-Lussac ascended alone to a height of 23,000 feet on September 16, 1804, in a balloon filled with hydrogen. His observations confirmed those which he had made with Biot, that there was no change in the magnetic force, and from samples of air collected he proved that the chemical constitution of the air is invariable. His observations of temperature seemed to confirm the theory of a decline of temperature of 1° in 300 feet of elevation. The air was found to be very dry, and Gay-Lussac noticed that at the highest altitude the clouds were still far above him.

Passing over several notable ascents in other countries, it was not until 1850 that scientific ballooning was begun again in the land where the balloon originated. Then MM. Barral and Bixio made two ascents from Paris in rainy weather to the heights of 19,000 and 23,000 feet respectively, although they had expected to attain twice these altitudes. Their most interesting observations were

the great thickness of the cloud mass, which in one case amounted to 15,000 feet, and the sudden fall of temperature in it from $+15°$ to $-39°$. Some curious optical phenomena were connected with the floating ice crystals, and although the light of the sky was found to be strongly polarized, the light reflected from the clouds was not polarized.

The field of operations was now transferred to England, where, under the auspices of the British Association, four ascents were made by John Welsh of the Kew Observatory in the great *Nassau* balloon managed by Green, the veteran aeronaut. The special object of these investigations, like those in France, was the determination of the temperature and hygrometric condition of the air at different elevations. Besides this, samples of air at different heights were collected for analysis and the light reflected from clouds was examined for polarization. Recognizing that on account of the calm prevailing in the car of the balloon and the great solar radiation, the readings of the thermometer would be affected, Welsh enclosed the thermometers in polished tubes through which air was forced by bellows. This was the first aspirated thermometer, which alone gives the true temperature of the air with the conditions prevailing in a balloon. The instrument fell into oblivion until a few years ago, and to this fact is

due the fictitious temperatures generally obtained by aeronauts. Welsh reached heights of from 12,500 to 23,000 feet, and his observations showed that the temperature of the air decreased uniformly with height until at a certain elevation, varying on different days, the decrease is arrested, and for a space of 2000 or 3000 feet the temperature remains nearly constant, or even increases slightly; the regular diminution being afterwards resumed and generally maintained at a less rapid rate than in the lower air, and commencing from a higher temperature than would have existed but for the interruption. The variation of the decrease with the seasons was also demonstrated. The humidity did not change much with height, and it was nowhere very dry. Finally, the light of the clouds was proved not to be polarized, and the permanent composition of the atmosphere was confirmed.

In 1861 another grant of money was made by the British Association for balloon experiments to be performed, under the direction of a Committee, by Mr. James Glaisher, then engaged in geodetic and meteorological work in England. Between 1862 and 1868 Glaisher, accompanied by the aeronaut Coxwell, made thirty ascents. They attained three times a height exceeding 23,000 feet, and once more than 29,000 feet, when they believed that the balloon rose to 37,000 feet. The primary objects of

Glaisher's experiments were as follows: determination of the temperature of the air and its hygrometrical conditions up to five miles, comparisons of an aneroid barometer with a mercurial one, determination of the electrical state of the air and of its oxygenic state by means of ozone papers, time of vibration of a magnet at different distances from the earth. Secondary objects of study were the composition of the air, the form and thickness of clouds, the atmospheric currents, acoustical phenomena, etc. In order to obtain many observations frequent ascents were necessary, as the insular position of England precluded long voyages. During 1869 ascents in a captive balloon up to 1700 feet supplemented the employment of the free balloon, which from its rapid rise and fall made observations in it near the earth impossible. Glaisher was a good observer; his instruments were excellent, and had been previously tested, but their exposure in the basket of the balloon was bad, and although the thermometer was provided with an aspirator similar to Welsh's, Glaisher, noticing that the readings agreed with those of a freely exposed thermometer, hastily concluded that the use of the aspirator was unnecessary, and so discarded it.

Until quite recently Glaisher's results were accepted as representing the conditions of the free

air up to the greatest height which it was possible to reach. These results showed that the temperature did not fall uniformly with height, but that it fell most rapidly near the earth and much less rapidly at great heights. In cloudy weather up to the height of a mile the mean decrease of temperature in the daytime differed little from the theory of 1° per 300 feet, but in clear or partly clear weather the decrease was more rapid, commencing with 1° for 160 feet near the ground and diminishing to 1° for 1000 feet at an elevation exceeding six miles. The observations in the captive balloon up to a third of a mile indicated a daily range in the vertical decrease of temperature. The observations of relative humidity agreed with Welsh's in showing a slight increase up to about half-a-mile, then a decrease up to above five miles, where there seemed to be an almost entire absence of water. The other observations were inconclusive, except that the time of vibration of a magnet was found to be somewhat longer than on the earth, which was contrary to Gay-Lussac's experience. The most remarkable of Glaisher's ascents was made from Wolverhampton on September 5, 1862, when in less than one hour he had passed the altitude of five miles, exceeding the greatest height hitherto reached. To quote from Glaisher's narrative: "Up to this time I had taken observations with comfort and experi-

enced no difficulty in breathing, whilst Mr. Coxwell, in consequence of the exertion he had to make, had breathed with difficulty for some time. Having discharged sand, we ascended still higher; the aspirator became troublesome to work, and I also found a difficulty in seeing clearly. . . . About 1 hour 52 min., or later, I read the dry-bulb thermometer as minus 5°; after this I could not see the column of mercury in the wet-bulb thermometer, nor the hands of the watch, nor the fine divisions of any instrument. I asked Mr. Coxwell to help me to read the instruments. In consequence, however, of the rotatory motion of the balloon, which had continued without ceasing since leaving the earth, the valve-line had become entangled, and he had to leave the car and mount into the ring to readjust it. I then looked at the barometer, and found its reading to be 9¾ inches, still decreasing fast, and implying a height exceeding 29,000 feet. Shortly after, I laid my arm upon the table, possessed of its full vigour, but on being desirous of using it, I found it powerless . . . Trying to move the other arm, I found it powerless also. Then I tried to shake myself and succeeded, but I seemed to have no limbs. . . . I dimly saw Mr. Coxwell, and endeavoured to speak, but could not. In an instant intense darkness overcame me, so that the optic nerve lost power

suddenly, but I was still conscious, with as active a brain as at the present moment whilst writing this. I thought I had been seized with asphyxia, and believed I should experience nothing more, as death would come unless we speedily descended; other thoughts were entering my mind, when I suddenly became unconscious. . . . I cannot tell anything of the sense of hearing, as no sound reaches the air to break the perfect stillness and silence of the regions between six and seven miles above the earth. My last observation was made at 1 hour 54 min., above 29,000 feet . . . Whilst powerless I heard the words, 'temperature' and 'observation,' and I knew Mr. Coxwell was in the car speaking to and endeavouring to rouse me. . . . I then heard him speak more emphatically, but could not see, speak, or move. I heard him again say, 'Do try; now do!' Then the instruments became dimly visible, then Mr. Coxwell, and very shortly I saw clearly. . . . Mr. Coxwell told me that while in the ring he felt it piercingly cold, that hoarfrost was all round the neck of the balloon, and that on attempting to leave the ring he found his hands frozen. He had, therefore, to place his arms on the ring and drop down. . . . He wished to approach me, but could not; and when he felt insensibility coming over him too, he became

anxious to open the valve. But in consequence of having lost the use of his hands he could not do this ; ultimately he succeeded, by seizing the cord with his teeth, and dipping his head two or three times, until the balloon took a decided turn downwards. No inconvenience followed my insensibility ; and when we dropped, it was in a country where no conveyance of any kind could be obtained, so I had to walk between seven and eight miles. . . . I have already said that my last observation was made at a height of 29,000 feet ; at this time (1 hour 54 min.) we were ascending at the rate of 1000 feet per minute ; and when I resumed observations we were descending at the rate of 2000 feet per minute. These two positions must be connected, taking into account the interval of time between, viz. 13 minutes, and on these considerations the balloon must have attained the altitude of 36,000 or 37,000 feet. Again, a very delicate minimum thermometer read minus 11°.9, and this would give a height of 37,000 feet. Mr. Coxwell, on coming from the ring, noticed that the centre of the aneroid barometer, its blue hand, and a rope attached to the car were all in the same straight line, and this gave a reading of seven inches and leads to the same result. Therefore, these independent means all lead to about the same elevation, viz. fully seven miles."

Mr. Glaisher's circumstantial evidence of the height he reached has been assailed lately, partly from his assumption that the velocity of the balloon while rising and falling during the thirteen minutes was uniform, but principally from the supposition that men could have survived in that region of death, without at least artificial means of respiration. While it is certain that Berson's observations, which are described later, were made at a greater height than Glaisher's, yet all credit must be given to this Nestor of aeronautical and meteorological science in Great Britain, who is still living at the advanced age of ninety.

The example of Glaisher was not followed in England, but it stimulated interest in the balloon again in France, where MM. Flammarion, de Fonvielle, and Tissandier have made many ascents for scientific purposes, and have presented the results in a popular form to the public. Photography in a balloon is generally a failure on account of the intense reflection from the upper cloud surfaces and the haze which masks the earth. Consequently, for scenic effects we must rely upon sketches, of which those in that interesting, but now rather rare book, *Travels in the Air*, may be referred to. The high atmosphere is often filled with fine ice crystals which, though invisible from below, occasion curious optical phenomena, and

some of these have been sketched by M. Albert Tissandier, who has the advantage of being an artist as well as an aeronaut.

Of the many narratives of balloon voyages, one of the most thrilling is the tragedy of the *Zenith.* In 1875, through the co-operation of the French Academy of Sciences and other scientific bodies, it was arranged to make two voyages, one of long duration, the other to a great height, in the balloon *Zenith.* The long voyage from Paris to Bordeaux was successfully accomplished in twenty-four hours, and on April 15 the *Zenith* again rose from Paris, carrying MM. Gaston Tissandier and Crocé-Spinelli, with Sivel as aeronaut. By the advice of M. Paul Bert, the distinguished physiologist, three small balloons of oxygen were provided to assist respiration. The scientific apparatus was as follows: a pump was arranged to draw air through tubes filled with potash in which to store the carbonic acid at different heights in the atmosphere, in order that analysis might determine if its proportion diminished at great heights; a spectroscope was employed to examine the line of water-vapour in the atmosphere, and two aneroid barometers were provided, one giving the pressure corresponding to heights up to 13,000 feet, the other the pressure between 13,000 and 30,000 feet. There were also two barometric tubes registering

the lowest pressure, as well as thermometers and other scientific instruments. At 15,000 feet the voyagers began to breathe oxygen, which had been used beneficially by Sivel and Crocé-Spinelli in a high ascent the previous year. At 24,000 feet Tissandier wrote in his notes: "My hands are freezing. I am well. We are all right. Haze on horizon with small rounded cirrus. We are rising. Crocé pants. We breathe oxygen. Sivel shuts his eyes, Crocé does the same." Five minutes later: "Sivel throws out ballast, temperature $-11°$ Cent., barometer 300 millimeters." After this, Tissandier became so weak that he could not turn his head to look at his companions. He tried to seize the oxygen tube, but was unable to move his arms. His mind was clear, and he saw the barometer sink below 280 millimeters, indicating a height of 27,000 feet. Then he fainted. After a half-hour of unconsciousness he revived and wrote: "We are falling, temperature $-8°$, barometer 315 millimeters. I discharge ballast. Crocé and Sivel unconscious in bottom of basket. We fall rapidly." Again he fell into a stupor, from which he was roused by Crocé shaking his arm, saying, "Throw out ballast!" which he did, together with the pump, wraps, etc. What happened after this is unknown, but probably the balloon, thus lightened and the gas in it being warm, rose again nearly as

high as before. When Tissandier came to his senses the balloon was falling with frightful speed, and in the bottom of the basket, which was oscillating violently from side to side, were crouched his two companions with black faces and bloody mouths. The shock of striking the ground was terrific, but the anchor held, and the balloon soon emptied. From the barometric data it appears probable that the *Zenith* attained twice a height of about 28,000 feet, and that asphyxiation from the long deprivation of sufficient oxygen killed the two companions of Tissandier and nearly proved fatal to him.

This disaster discouraged further attempts to reach high altitudes, and with the exception of the ascent to 23,000 feet in France by MM. Jovis and Mallet, no more were made until the past decade. The results of the meteorological observations were seen to be strangely discordant; for example, the temperature of 40° below zero, observed by Barral and Bixio at a height of 23,000 feet, and 80° above zero, noted by the American aeronaut Wise, at 6000 feet. The prophecy "that the balloon-basket would be the cradle of the young science of meteorology" seemed unlikely to be realized, but, nevertheless, observations in balloons continued to be made in France, Italy, and Russia. In the United States a series of balloon ascents

was conducted by the Signal Service, which then included the Weather Bureau, and the height of 15,500 feet reached by Professor Hazen in 1887 is probably the greatest at which observations in the free air have been made in America.

The difficulty of obtaining the true temperature of the air from a balloon is great, and without special precautions the observations give the conditions of the free air even less well than do observations on mountain summits. During a rapid ascent the air is carried up in the balloon basket like water in a well-bucket, and since the balloon drifts with the wind it is relatively in a calm, so that there is no circulation of air; the thermometers, even when screened from direct sunshine, are affected by radiation from the heated gas-bag above, and moreover they are not sufficiently sensitive to follow the changing temperature of the air strata so quickly traversed by the balloon. The aneroid barometer, from which the height of the balloon is calculated, cannot respond to rapid changes of pressure; consequently there is a double source of error in determining the height at which the temperature is measured. Ordinarily, the temperature of the air may be obtained quite accurately by slinging in a circle a thermometer attached to a cord, even though this is done in sunshine. During two balloon

ascents by the writer, a sling thermometer was found in extreme cases to read 14° lower than was recorded by automatic instruments, hung in their usual position from the ring of the balloon. The sling thermometer, however, is influenced by intense insolation, and moreover cannot be swung far enough outside the basket of a balloon to insure good results. The standard instrument for obtaining the temperature of the air under all conditions, adopted for international use in 1898, is a modification of that used by Welsh forty-five years before. This instrument, which is the invention of Dr. Assmann of Berlin, is called the aspiration thermometer, and is designed to prevent the casing surrounding the thermometer from being heated by insolation or conduction, and to insure a flow of air past the thermometer bulbs.

The reorganization of balloon observations was accomplished by the German Society for the Promotion of Aërial Navigation, which has been assisted by the Prussian Meteorological Institute, and by officers of the German Army Balloon Corps. The German Emperor takes a personal interest in the work, and has aided it by the gift of a considerable sum of money. The first voyage under the direction of the Society was made in 1888, and many notable ones followed. In 1891, through the courtesy of the president, Dr. Assmann,

the writer made an ascent from Berlin in a balloon equipped for accurate observations, with the special

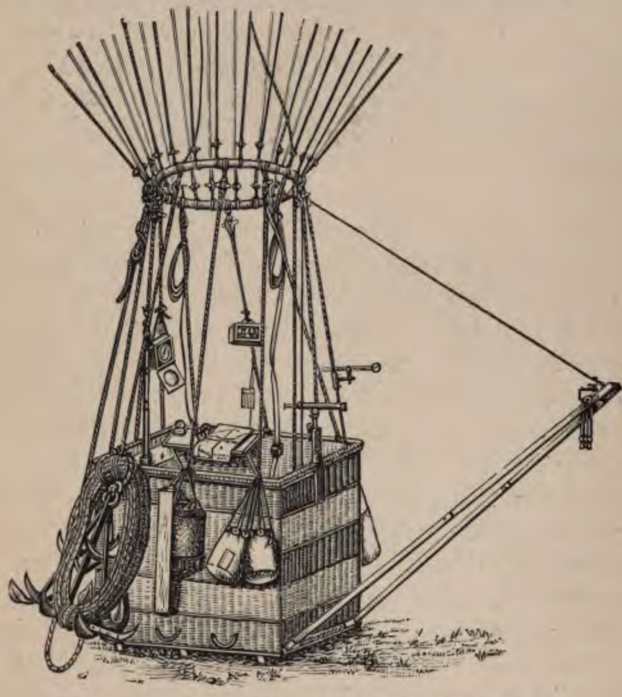

FIG. 3.—German Balloon equipped for Meteorological Observations.

purpose of comparing the sling with the aspiration thermometer. The car of the balloon is shown in Fig. 3. A companion was the now famous Dr.

Berson, who then made his second ascent, but who has now become an expert aeronaut by reason of more than fifty ascensions, some of them to great heights. On December 4, 1894, he ascended alone from Stassfurt, Prussia, in the *Phœnix*, to probably the greatest height ever reached by man, at least in a conscious state. By breathing oxygen he was able to keep his senses and to read the barometer at 9·1 inches, indicating approximately an altitude of 30,000 feet, and the aspirated thermometer at 54° below zero. An ordinary thermometer read 11° below zero in the sun, showing its heat was much diminished in consequence of the haze that prevailed even at this enormous height. The cirriform clouds which surrounded the balloon were found to have the structure of snow-flakes rather than that of ice-crystals. The chief result of this record-breaking ascent was the extraordinarily low temperatures recorded at great heights, as compared with those observed by Glaisher, Tissandier, and others. An inversion of temperature—that is an increase of temperature with height—prevailed up to a mile, but above that the temperature fell at a rapid and accelerated rate which approached the adiabatic fall above 26,000 feet. The wind, which was almost calm at the earth's surface, increased to a gale in the high atmosphere, and carried the balloon along at an average speed of thirty-six

miles an hour. Wishing to demonstrate conclusively whether the insular position of England influenced the temperature of the high atmosphere, as had been suggested, Dr. Berson determined to execute a high ascension in England during the prevalence of a barometric maximum in summer, when the air column would be abnormally warmed and the upper isothermal surfaces elevated. An opportunity was afforded Berson to follow in Glaisher's footsteps on September 14, 1898, when abnormal heat prevailed in Europe. Berson, with the aeronaut Spencer, in the balloon *Excelsior*, rose from the Crystal Palace in London to the height of 27,300 feet, where he observed a temperature of $-29°$. The oxygen inhaled prevented harmful physiological effects except for the discomfort caused by the enormous reduction of temperature from 80° at the ground only thirty-five minutes before. The temperature decreased rapidly at first, then moderately up to three miles, and above that it fell almost at the adiabatic rate. Even in this hot summer maximum of pressure and notwithstanding the maritime climate and south-westerly currents, a temperature about 29° below zero reigned at 27,000 feet, being only a few degrees warmer than Berson had observed in winter at the same height above Germany. Yet Glaisher, in all his ascents, two of which exceeded 26,000 feet, never re-

corded a temperature of less than 5° below zero. These relatively high temperatures, obtained also by Welsh, Tissandier, and Gay-Lussac, must be attributed to the insufficient protection of the thermometers against insolation, to the proximity of the instruments to the heated basket and its occupants, and lastly, to the sluggishness of the thermometers themselves, from lack of ventilation, during the rapid passage through air-strata of different temperatures. Plate VI. indicates the change of temperature with height observed during the four highest balloon ascents in Europe and in the United States. Dots indicate the observations while ascending, and crosses the observations while descending; these are connected by full and broken lines respectively, an inclination upward to the left showing a decrease of temperature with height and *vice versâ*. The adiabatic lines, representing a fall of temperature of 1° Fahrenheit per 183 feet of ascent, serve for comparison.

This account of notable balloon ascents should not be closed without mentioning the most daring and unique of all, the voyage of Mr. S. A. Andrée towards the north pole in 1897. Although his was a voyage of geographical discovery, and not one for the exploration of the air, yet meteorological and other observations were to be made, and Andrée had familiarized himself with the instruments and

the management of a balloon during several voyages in Sweden. The success of the polar voyage depended primarily upon the prevalence

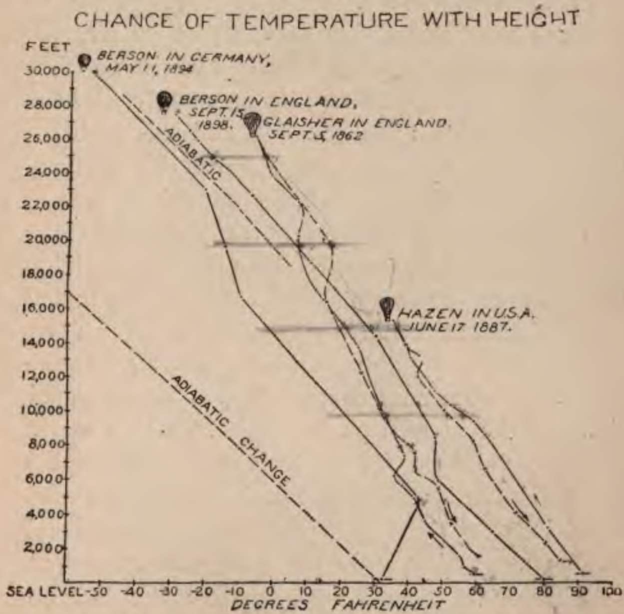

PLATE VI.—TEMPERATURES OBSERVED IN FOUR HIGH BALLOON ASCENTS.

of southerly winds, and the ability of the balloon to keep afloat long enough to profit by them, even should they be light and variable at times. Therefore the impermeability of the balloon to hydrogen

gas was of vital importance, and it was the conviction that the *Eagle*, of 140,000 cubic feet, was neither sufficiently large nor staunch to sustain itself for thirty days, the time which might be required to reach Behring Straits, that led Dr. Nils Ekholm, the meteorologist and physicist, to withdraw from the expedition. Unfortunately, his fears seem to have been well founded, and it is probable that we must now abandon hope of the safety of the brave Andrée and his two companions.

A less perilous voyage northward across the Alps was attempted in 1898 by Professor Heim, the Swiss geologist, and two associates, conducted by the Italian aeronaut, Spelterini. With an automatic photographic camera, similar to one described in the next chapter, it was hoped to get views of the high Alps from above, which would be alike valuable for geologic and topographic study. Extensive meteorological observations were made in connection with the sixth international balloon ascent, but only the Jura was crossed, at an altitude of 13,000 feet, because the balloon travelled in a north-westerly direction, instead of north-east as was expected.

Many years ago Wise and Donaldson, the American aeronauts, proposed to cross the Atlantic Ocean in a balloon. The difficulties which present themselves in such an undertaking are purely

technical, and given a balloon which loses its gas so slowly that its buoyancy can be maintained for several days, there seems to be no reason why such a balloon, at a height of four or five miles, could not pass from San Francisco to New York, or from the United States to Europe, since the motion of the upper clouds proves that the high atmosphere moves almost constantly with great velocity from the west to the east. The dirigible balloon has not been realized except in nearly calm weather, but the aeronaut can often reverse his direction by ascending or descending into a contrary wind to that in which he has been travelling. Frequently no clouds separate these opposing currents, which become apparent only when a balloon enters them.

It has been mentioned that in 1869 Glaisher made observations in a captive balloon in England up to the height of 1700 feet in order to study the conditions of the air within this distance of the earth, which could not be done in a free and rapidly moving balloon. Although captive balloons are frequently used in the European cities to lift people who wish to enjoy the view from a height of 500 or 1000 feet, they appear to have been little used by scientific observers since the time of Glaisher. In 1890–91 the aeronautical society at Berlin employed a captive balloon in connection with the observations in free balloons which have

been described. This captive balloon had a capacity of only 5000 cubic feet, but it sufficed to lift an apparatus weighing sixteen pounds, designed by Dr. Assmann to record atmospheric pressure, as well as the temperature and relative humidity of the air. The balloon, attached to a cable 2600 feet long, was drawn down by a steam engine. It was possible in this way to have simultaneous observations at three levels, viz. near the ground, in the free air at a height of about half-a-mile, and at the highest level attained by a free balloon. But the captive balloon is often at a disadvantage, for the wind drives it down, and although the meteorograph mentioned had ingenious devices to neutralize the violent shocks caused by this and by the rebound of the balloon after the gust of wind, yet these impaired the automatic record. The height to which the balloon rose was so much diminished by the wind that instead of 2600 feet, which the balloon attained in calm weather when the cable was vertical, the average height of the twenty-four ascents was but half this, and in very windy weather the balloon could not rise at all.

To obviate these difficulties, a few years ago there was invented by two officers of the German army, Lieutenants von Siegsfeld and von Parseval, a captive balloon capable of resisting strong winds, called, from its action as a kite, the *Drachen-*

Ballon or kite-balloon, and which at the present time is being successfully used in the German

FIG. 4.—German Kite-balloon.

Army and Navy for reconnoitring in all kinds of weather. A smaller kite-balloon, of 7700 cubic

feet capacity, filled either with hydrogen or with illuminating gas, was first used to lift meteorological instruments at Strassburg in 1898, where it remained at a height of several hundred feet during twenty-four hours. As is seen from Fig. 4, the balloon is cylindrical, with hemispherical ends, and is attached to its cable like a kite, so that the wind acts to lift and not to depress it. The cylinder is divided by a diaphragm near its lower end into two chambers, the upper and larger one being filled with gas, while the lower chamber, by means of a valve opening inwards, receives the pressure of the wind which presses against the diaphragm, and preserves the sausage-like form of the balloon in spite of leakage of gas. Another wind-bag encircling the bottom of the air-chamber serves as a rudder, and lateral fins or wings give stability to the balloon about its longer axis. The instruments are placed in a basket hung far below the balloon. In cases where there is little or no wind at the ground, captive balloons can render valuable service for meteorological observations, but in all other cases kites are preferable. The reasons for this assertion will be given when we consider kites.

From what has been said it will be perceived how much the Germans did to advance scientific ballooning, yet their constant rivals, the French,

found a way to surpass them in the exploration of the atmosphere. For several years the struggle for supremacy in the attainment of the greatest heights was keen between the scientific men of both countries, but a truce was declared at Paris in 1896, and since then both nations have worked together harmoniously. The friendly meeting of French and German physicists at Strassburg in 1898 to agree upon the details of co-operation, typified the union of nations through science, and while it is true that the atmosphere has no boundaries and cannot be pre-empted, let us hope that the common aims of science will ultimately obliterate even political boundaries.

CHAPTER IV

BALLONS-SONDES FOR GREAT ALTITUDES—THE INTERNATIONAL ASCENTS

WE have seen that the ascent of human beings to heights of six miles is attended with difficulty and danger, and even with apparatus for supplying the life-sustaining oxygen, man can hardly hope to reach much greater altitudes. Consequently, to obtain information about the atmospheric strata lying above six miles, that is to say, those facts which require to be ascertained in the medium itself, we must employ the so-called *ballons-sondes*, carrying self-recording instruments but no observers. This method, which was proposed in Copenhagen as long ago as 1809, was first put into execution by the French aeronauts, Hermite and Besançon, who, it may be remarked, suggested attempting to reach the North Pole by balloon some time before Andrée announced his scheme.

A balloon is the best of anemometers, since it

takes the direction and speed of the currents in which it floats, and hence it is customary, before a manned balloon starts, to dispatch several small pilot-balloons in order to judge of the direction and strength of the upper winds. Even if we do not know the height of the currents in which they float, though this can be ascertained by measuring the height of the balloon trigonometrically or micrometrically, we still obtain a general knowledge of the direction and speed of the currents. With this idea, M. Bonvallet in 1891 dispatched from Amiens, France, ninety-seven paper balloons, each provided with a postal card asking for the time and place of descent. Sixty of these cards were returned, almost all the balloons having been carried east by the upper current, ten going beyond one hundred and thirty miles, and one travelling at a speed of almost one hundred miles an hour.

The next year the experiment was continued by MM. Hermite and Besançon with balloons of thirty-five cubic feet contents, and about half of those dispatched from Paris were recovered within a radius of one hundred miles. The height to which the balloons could rise is determined by the following considerations: to ascend 18,000 feet, where the atmospheric pressure is one-half that at the earth (see Plate I.), the balloon when half full of gas must lift itself from the ground;

to rise 35,000 feet, where the pressure is reduced to one-quarter, it must be able to start upward when one-quarter filled, and so on. In practice the ascensional force usually diminishes at first from various causes, such as the escape of gas, its cooling, and the deposit of moisture on the outside of the balloon. To penetrate the clouds, therefore, it is necessary to have a considerable excess of ascensional force, but above the clouds, since the heating effect of the sun increases greatly with altitude, the gas in the balloon is warmed much above the surrounding air, and so the theoretical altitudes are exceeded.

Having determined that balloons inflated with one hundred and fifty cubic feet of coal-gas would rise to great heights, simple and light registering instruments, as well as the postal cards, were attached to them. As the pressure diminished, an aneroid barometer traced a line on a smoked glass, and after the descent was placed under the receiver of an air-pump, and the pressure required to reproduce the trace was measured by a manometer. From this the height could be computed approximately. The maximum and minimum thermometer was of the well-known U-form, and instructions appended asked that it be read as soon as found. A slow-match was arranged to detach postal cards successively, so that if they

were found and mailed, the track of the balloon could be determined. These balloons at first were called *ballons perdus*, or lost balloons, but when it was known that most of the fourteen balloons liberated from Paris were recovered, the name *ballons explorateurs* was given, which was afterwards changed to *ballons-sondes*, or sounding balloons. The Germans call them, *Registrir-Ballons*, and in English they have been designated unmanned balloons also. One of these paper balloons having reached a height of nearly 30,000 feet, MM. Hermite and Besançon proceeded to construct a balloon of gold-beater's skin, having a capacity of 3960 cubic feet, in order to carry a better instrumental equipment. The self-recording instruments made by the French firm of Richard Brothers were well adapted for this purpose, and a combined barometer and thermometer, registering in ink on an upright drum that is turned by clock-work inside, is shown in Fig. 5. The exhausted pair of boxes B of the barometer actuates the lower pen, while the curved tube C, which is filled with alcohol, by its change of shape moves the upper pen and records the temperature. From the indications of the barometer and the temperature of the mass of air, it is possible by Laplace's formula to calculate the height at any hour of the registration. The balloon mentioned was the first

of the so-called *Aérophiles*, and when inflated with coal-gas it could lift seventy-seven pounds besides its own weight of forty pounds. It carried two of the baro-thermographs described, and a package of information cards arranged to be detached by a slow-match. To mitigate the shock of striking the ground one of the instruments was hung by rubber cords inside a wicker basket that in the first ascent was not screened from the sun. It was

FIG. 5.—Baro-thermograph of Richard.

decided to liberate these balloons entirely filled with gas (instead of partly full, to allow for its expansion), and to utilize all possible ascensional force at first rather than to weight the balloon with an automatic discharger of ballast (Fig. 6). The trial of the *Aérophile* occurred March 21, 1893, and the next day one of the cards was returned announcing its fall in the department of the Yonne, where the balloon and the instruments were recovered injured. From the blurred traces of the

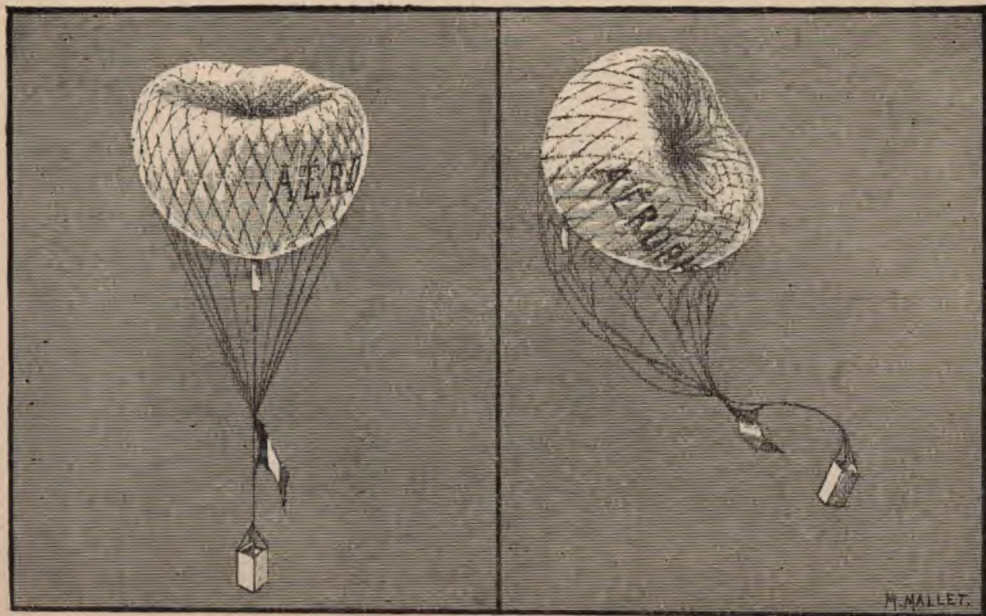

FIG. 6.—The *Aérophile* rising. The left-hand picture shows the deformation caused by the resistance of the air to its rapid ascent, and the right-hand one the violent oscillations when first liberated.

latter it was computed that at an altitude of about 49,000 feet a temperature of $-60°$ Fahrenheit had been met with, both pressure and temperature being the lowest measured in a balloon up to that time. Although the data secured by this ascent were somewhat doubtful, yet the feasibility of exploring the atmosphere by *ballons-sondes* was proved. It was seen that the enormous velocity of ascent overcame the wind and permitted the path of the balloon to the summit of its trajectory to be followed, the balloon appearing like a meteor visible in daylight, and so its height could be calculated by trigonometrical measurements; while the descent, caused by the escape and cooling of the gas, was gentle and regular, permitting the delicate instruments to be recovered uninjured.

The second ascent of this *Aérophile* was its last, for, after falling in the Black Forest, it was burned by children. However, M. Besançon, not discouraged, constructed the *Aérophile II.* of 6300 cubic feet, and improved the instruments as experience suggested. The records had often been interrupted by freezing of the ink, so the pen was replaced by a needle marking with less friction on smoked paper surrounding the record drum. To avoid heating of the thermometers by the sun, they were placed in a wicker cylinder open at both ends and covered with bright metallic paper.

This was hung below the balloon with its axis vertical, in order that the draught through the cylinder when the balloon was rising or falling should counteract the insolation, and in the next ascent, at about the same altitude, a temperature lower by 36° Fahrenheit indicated the effect of the protection. To secure an independent record of the lowest temperature an ingenious device was used, consisting of a thermometer tube filled with alcohol and having black divisions. The lowest point to which the alcohol sank was recorded on photographic paper placed behind the tube, the whole being enclosed in a metallic box that was automatically closed on striking the ground, and so was preserved against the meddling of curious persons. Up to the middle of 1898 ten voyages had been made by the *Aérophiles*, which were now constructed of varnished silk to hold 16,000 cubic feet of gas.

One of the objects sought was the collection of samples of air at great heights, but this was not accomplished until recently. In the first apparatus for this purpose, an aneroid barometer at a predetermined pressure turned the cock communicating with an exhausted receiver that filled with air and was then closed. The cock leaked, so next the ingenious device of generating heat chemically to seal the glass tube was tried. This, too, failed,

but finally, an apparatus of M. Cailletet solved the problem. It is advisable to control the height deduced from the barometric records by direct observations so long as the balloon remains visible, and for this purpose micrometric measures were made with a telescope as soon as the balloon left the ground. There was also used a species of registering theodolite which, when kept pointed at the balloon, automatically traced on paper its azimuth and angular altitude. These records, when combined with the barometric height at a known hour, permitted the horizontal distance traversed, and hence the velocity, to be calculated, or, with two such instruments at ends of a base line, the height of the balloon could be found.

The first experiments with *ballons-sondes* in France were soon repeated in Germany, where a balloon of rubber-fabric holding 8700 cubic feet was obtained by the German Society for the Promotion of Aërial Navigation. When inflated with coal-gas it had a lifting force of about two hundred and ninety pounds, in excess of its envelope, etc., weighing ninety-three pounds, and the meteorological apparatus weighing six pounds. The *Cirrus*, as it was called, burst on its first trial, but in July 1894 it made a remarkable voyage from Berlin to the boundary of Bosnia, a distance of seven hundred miles, at an average speed of

sixty-two miles an hour. A maximum height of 54,000 feet and a minimum temperature of $-63°$ Fahrenheit were recorded. The *Cirrus* on its third voyage was accompanied by manned balloons in order to have simultaneous observations at different levels, and this time it travelled eighty-three miles an hour and rose 61,000 feet. The lowest temperature of $-88°$ Fahrenheit was supposed to be too high, for the reason that whereas the ventilation of the thermometers in a rapidly ascending or descending balloon might be sufficient to counteract solar radiation, this would not be the case when the balloon was approaching its culminating point with a diminishing speed. Therefore, Dr. Assmann, under whose supervision the German experiments were conducted, employed the thermometer, which in the captive balloon was aspirated electrically, but now was driven by a weight, and later, because the ink froze, the registration was made photographic. The efficacy of the aspirator was seen in the ascent referred to, for, when its action stopped, a higher temperature was recorded though the balloon continued to ascend. In April 1895 the *Cirrus* rose to the extraordinary height of 72,000 feet, or more than thirteen and a quarter miles, where the barometric pressure was reduced to one and a half inches of mercury. (In Plate I. this extreme and possibly excessive height is not

shown as the height of the *ballon-sonde,* but the average of the three highest ascents of the *Cirrus* is indicated.) The comparative warmth ($-50°$ Fahrenheit) recorded has led Dr. Assmann himself to doubt the accuracy of the usual methods of registering temperature at such extremely low pressures. Plate VII. shows the heights in metres, and the temperatures in degrees Centigrade, during eight voyages from Berlin prior to June 1897.

Notwithstanding the rivalry and difference of opinion between the Germans and French as to the methods of exploring the high atmosphere, there was also a sincere desire to co-operate, and the International Meteorological Conference which was held at Paris in September 1896 furnished an opportunity to make the arrangements. Resolutions were adopted favouring ascents with manned balloons, as well as simultaneous ascents of *ballons-sondes* in the different countries. The successful use of kites at Blue Hill to lift self-recording instruments more than a mile into the air led to the wish that similar experiments should be tried elsewhere. An International Committee was appointed to carry out these resolutions, of which Professor Hergesell of Strassburg is president, and the veteran Parisian aeronaut and journalist, Wilfrid de Fonvielle, is secretary.

It was agreed to make a night ascent and to use

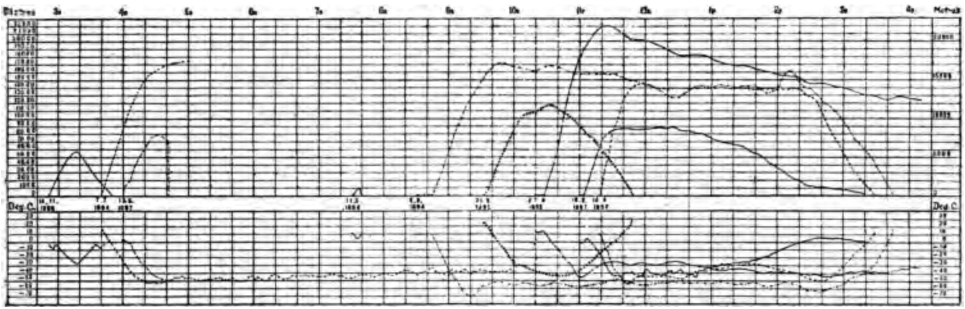

Plate VII.—Heights and Temperatures recorded in eight ascents of the *Cirrus*.

identical instruments, in order that the observations might be made everywhere under the same conditions. Accordingly, on the early morning of November 14, 1896, five balloons manned by observers, and three *ballons-sondes* with recording instruments, were liberated in France, Germany, and Russia. By means of the automatic diagrams from the *ballons-sondes*, and the direct observations in the manned balloons, it was sought to determine the decrease of temperature with height in vertical sections of the atmosphere connecting the various centres from which the balloons started. Seven such sections were available by connecting Paris and Strassburg, Berlin and St. Petersburg, Warsaw and Munich, etc., but, unfortunately, observations in the highest strata were generally lacking.

Three more international ascents were made during the year 1897, which were participated in less extensively. At this time it was necessary to decide questions that had arisen, and to make plans for the future, consequently a meeting of the International Committee was held at Strassburg in 1898. Many technical questions were settled, but the chief result accomplished was the dissipation of misunderstandings and prejudices, not only between French and Germans, but between the German representatives themselves, for no doubt personal intercourse is the greatest good of such conferences.

Although it was not a surprise, nevertheless it was regretted that no one came from Great Britain, where, since Glaisher's epoch-making balloon ascensions, little has been done to explore the air. The beneficial results of the Conference were apparent at the fifth international ascent, which occurred in the early morning of June 8, 1898. Austria and Belgium joined Germany, France, and Russia, and the field of atmospheric survey was extended over a good part of Europe. A veritable aeronautic fleet was launched from Paris, Brussels, Berlin, Warsaw, St. Petersburg, Strassburg, Munich, and Vienna, consisting of twenty-one balloons, of which thirteen carried observers, who all used the aspiration thermometers, and eight were equipped only with self-recording instruments. Some of the latter balloons reached altitudes of 50,000 feet, and the former attained extreme heights of one-third this. On the day selected the atmosphere was in a state of repose, with light variable winds, except high up, where they blew, as is usual, from the west or south-west. These observations were sufficiently numerous to form a synoptic chart at a considerable height above Europe for comparison with the usual chart drawn from the surface observations.

Besides the general work of the International Committee, special investigations have been undertaken by the French, who formed an Aerostatic

Commission in Paris. The services of the eminent physicists, MM. Cailletet and Violle, have been enlisted, while a generous patron has been found in Prince Roland Bonaparte. The apparatus of M. Cailletet to bring down samples of air from the high regions may now be described. When the balloon has reached its greatest height a cock of special construction, turned by clockwork, opens and allows the air to enter a reservoir in which a vacuum exists, and then the cock is automatically and hermetically closed. As it is known that the balloon reaches its extreme height in about an hour and a quarter, the time of opening the cock is so regulated, the closing taking place a little later by its further rotation. In order to protect the moving parts from the extreme cold, a receptacle filled with fused acetate of soda is placed in the box containing the motor, so that, notwithstanding the intense cold of the high regions, this salt in assuming a crystalline state gives out enough heat during several hours at least. During the ascent of an *Aérophile* air was collected at 50,000 feet, which when analyzed by M. Müntz showed what was supposed, viz. that at this altitude the composition of the air does not differ much from that of the lower air. The slight excess of carbonic acid found in the upper air might be due to the oxidation of the grease used on the cock,

and the smaller quantity of oxygen, as compared with normal air, might be caused by the absorption of this gas by the grease or even the absorption by the tinned sides of the copper reservoir. By eliminating all possible sources of error in future ascensions, M. Müntz thinks that it can be proved whether there are real differences in the air at different heights, for the methods of analysis are to-day accurate enough to show such differences if they exist. But since it is probable that in the regions which can be explored by the *ballons-sondes*, the air undergoes the same mixing that renders the lower air nearly uniform, only the smallest variations in its composition would naturally be found, requiring minute precautions against errors. This is no doubt why previous measures agreed in showing the invariable composition of the air at lower altitudes.

Another important contribution of M. Cailletet is an apparatus for measuring the height of the balloon by photography in order to verify Laplace's formula connecting the barometric pressure with the altitude. The idea was to replace the observers on the ground, who sometimes made the trigonometrical measurements of the balloon described, by a photographic apparatus carried by the balloon itself, and which at frequent intervals should photograph automatically the ground over

which it passed, at the same time that an aneroid barometer was photographed on the same sheet. The apparatus is hung vertically below the balloon; in the lower portion of the box is an objective which photographs the ground, and in the upper portion is a second objective which photographs the face of an aneroid barometer placed at the proper distance above. A clock-movement makes exposures every two minutes, and a sensitive film unrolled between the objectives receives the images on each side. If there are known, the focal length of the objective, the distance of two points on the ground, and the distance of two points on the photograph, a simple proportion permits the height of the balloon to be determined at that time, and consequently, from the barometric record, the law connecting the pressure with height can be deduced. The apparatus was successfully used in the voyage of a large balloon with observers, and the accuracy of the determination of height was found to be within $\frac{1}{250}$. If the apparatus is to be used at great heights it would be necessary to protect the barometer and the camera from the very low temperatures. Besides the use for which it was designed, this apparatus may serve to trace the route of a balloon and to determine the horizontal velocity at the different points of its path.

The exploration of the high atmosphere by

ballons-sondes, which can aid so many investigations, has been utilized by M. Viollé to obtain actinometric measures, that is, to determine the amount of heat given by the sun, or what is called the "solar constant." This has been done on mountains with varying results, due to the changing amount of atmospheric absorption. In regions traversed by the balloon where the pressure of the air is reduced to a few inches of mercury, where there is a complete absence of water-vapour, and at heights to which terrestrial dust does not extend, the measure of the quantity of heat sent by the sun towards the earth is freed from almost all the errors which we encounter on its surface. The actinometer of M. Viollé is, in principle, a sphere of copper, blackened externally, and having inside a thermometric apparatus which registers some distance away. Under the action of the solar rays the sphere is heated, and assumes equilibrium when the loss by radiation and by contact with the air compensates for the gain by the absorption of the direct heat. While at low levels the atmosphere also contributes to heat the sphere, at great heights the sun shines from an almost black sky and alone heats the sphere. Since the balloon follows the wind the apparatus is protected from air currents which would otherwise introduce errors. Each twenty minutes a screen cuts off the

solar rays from the sphere so that it cools to the temperature of the air, which is also recorded. On account of its weight this apparatus has not yet been carried by a *ballon-sonde*, but it has operated successfully in a balloon with observers.

M. Teisserenc de Bort, who is actively engaged in exploring the air from a meteorological standpoint, has constructed a very sensitive thermometer made of a blade of German silver set in a frame of nickel-steel that does not expand with heat. This may be ventilated by a fan, and, while extremely sensitive to changes of temperature, it is not affected by shocks, and consequently is well adapted for use in *ballons-sondes* that pass rapidly through air-strata of varying temperature.

From this review of the development of the *ballons-sondes* it is evident that they offer possibilities of obtaining data in the high atmosphere, perhaps up to fifteen miles or more, which, though subject to inaccuracies, are of great interest to the physicist and astronomer. The meteorologist is chiefly concerned with that portion of the atmosphere which lies within two or three miles of the earth, and he requires, moreover, accurate measurements for his conclusions. The new and most satisfactory way of obtaining these data is by kites, and the remaining chapters will treat of this method of exploring the atmosphere and the results.

CHAPTER V

KITES—HISTORY AND APPLICATION TO METEOROLOGICAL PURPOSES AT BLUE HILL AND ELSEWHERE

KITES are supposed to have been invented four hundred years before the Christian era by Archytas, and at Smyrna the flying of kites remains a national sport to this day. We are told that two hundred years later, a Chinese general, Han Sin, employed kites as a means of communication with the garrison of a besieged town, and there is a legend about their use in Japan to dislodge and carry away a golden ornament from a tower. Whatever may be the truth of these stories, we know that kite-flying in the Malay Archipelago, in China, and in Japan, has been a pastime for all classes during centuries, and that the Asiatic people have always been the expert kite-fliers of the world.

Kites with tails seem to have been introduced into England about two hundred and fifty years

ago, and Isaac Newton when a school-boy made some improvements in them. Notwithstanding the fact that generations of boys have flown kites and so eminent a mathematician as Euler investigated their theory, until recently kites remained toys unsuited for practical purposes. Since the tailless kite has become a familiar object, it has been said facetiously that kites lost their tails by the same process of evolution which deprived man of his caudal appendage; but as kites without tails have been flown in Asia for centuries, the truth is that the tailed kites were the ones first brought to Europe as playthings. To-day in Holland we see boys flying the English bow-kite and the common kite with crossed sticks, both of which require tails, and by the side of them tailless kites imported from the Dutch colonies in Java. Fig. 7 represents a kite from the east coast of Java, drawn from a model in a museum at Amsterdam, and also a drawing of a Chinese bird-kite in the National Museum at Washington. Like most of the oriental kites, they are made flat, but when exposed to the wind the extremities of the wings, which have a frame of split bamboo, bend backward, securing in this way the stability which in our common flat kite is gained by the action of the tail in lowering the centre of gravity and in maintaining the inclination to the wind.

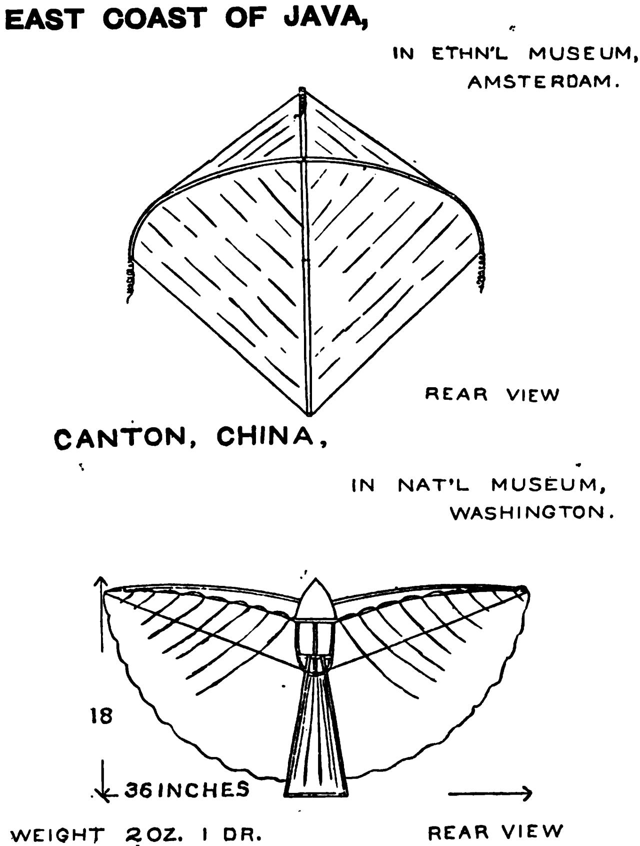

FIG. 7.—Oriental tailless Kites.

From historical researches that have been stimulated by the recent practical applications of kites, it appears that their first use for scientific purposes was in 1749, when Dr. Alexander Wilson of Glasgow, and his pupil, Thomas Melvill, used kites to lift thermometers. Their kites, from four to seven feet in height, and covered with paper, were fastened behind one another, each kite taking up as much line as could be supported, thereby allowing its companion to soar to an elevation proportionally higher. It is related that "the uppermost one ascended to an amazing height, disappearing at times among the white summer clouds, whilst all the rest, in a series, formed with it in the air below such a lofty scale, and that too affected by such regular and conspiring motions, as at once changed a boyish pastime into a spectacle which greatly interested every beholder. . . . To obtain the information they wanted they contrived that thermometers, properly secured, and having bushy tassels of paper tied to them, should be let fall at stated periods from some of the higher kites, which was accomplished by the gradual singeing of a match-line." How the thermometers were prevented from changing their readings while falling to the ground is not explained. The account concludes: "When engaged in these experiments, though now and then they communicated immediately with

the clouds, yet, as this happened always in fine weather, no symptoms whatever of an electrical nature came under their observation. The sublime analysis of the thunderbolt, and of the electricity of the atmosphere, lay yet entirely undiscovered, and was reserved two years longer for the sagacity of the celebrated Dr. Franklin." Hence it seems that Franklin's famous experiment of collecting the electricity of a thunder-cloud by means of a kite, performed at Philadelphia in 1752, was not its first scientific application, and therefore America can claim only the later and most remarkable development of this means of exploring the air.

About 1837 there existed in Philadelphia an organization called the Franklin Kite Club that flew kites for recreation. Espy, the eminent meteorologist, was a member, and he states "that on those days when columnar clouds form rapidly and numerously the kite was frequently carried upward nearly perpendicularly by columns of ascending air," a phenomenon which is often observed to-day. Espy calculated the height at which clouds should form by the cooling of the air to its dew-point, and then employed kites to verify his calculations of the heights of the clouds. It will be remembered that both these methods are utilized in the measurements of cloud-heights at Blue Hill. Kites were employed to get temperatures a hundred

or more feet above the Arctic ocean early in the present century, and in 1847 W. R. Birt flew a kite at Kew Observatory, with which he hoped to obtain measures of temperature, humidity, wind velocity, etc. This kite, hexagonal in shape, required three divergent strings attached to the ground to keep it steady, and the instruments were to be hoisted up to the kite by a pulley.

Perhaps the first person to soar aloft on a kite was a lady, who, more than fifty years ago, was lifted some hundred feet by a great kite constructed by George Pocock, an Englishman, to serve as an aërial observatory in warfare, and also to drag carriages along the ground. It was proposed afterwards to make use of kites in shipwrecks to take persons or life-lines ashore, and in 1865 Sir George Nares invented a storm-kite, so called, with a tail made up of hollow cones. This form of tail, subsequently used for both kites and balloons, is very efficient, since it offers increasing resistance as the wind becomes stronger.

In 1882 Mr. Douglas Archibald in England revived the use of kites for meteorological observations, and outlined a comprehensive scheme of exploring the air with kites which included almost all that has been done since, but his actual work, performed during the next three years, was limited to ascertaining the increase of wind velocity with

height. To do this, he attached registering anemometers at four different points on the kite-wire, but since the total wind movements only were registered from the time the anemometers left the ground until they returned, it was impossible to obtain simultaneous records near the ground and at the kite, as is done to-day. Still, Archibald got differential measurements of the velocity of the wind up to the height of 1200 feet. The kites he employed were diamond-shaped, covered with silk, and were flown tandem, with the hollow cones, already mentioned, attached to the tails. Although copper and iron wire had been used for flying kites many years before, yet Archibald was the first to substitute steel pianoforte wire for the string, thereby increasing the strength while diminishing the weight, size, and cost of the line. Mr. Archibald in 1887 took the first photograph from a kite, a method which MM. Batut and Wenz developed in France, and Messrs. Eddy and Woglom in the United States.

The subsequent progress of kite-flying for meteorological purposes has taken place in the last-named country, and may be chronologically stated as follows: in 1885 Mr. Alexander McAdie (later of the U. S. Weather Bureau) repeated Franklin's kite experiment on Blue Hill, with the addition of an electrometer; in 1889, and again

in 1892, he measured simultaneously the electric potential at the base of Blue Hill, on the hill, and with kites as collectors several hundred feet above the hill-top, about the same time that Dr. Weber, in Breslau, Germany, was making a more extensive use of kites for the same purpose. It was no doubt William A. Eddy of Bayonne, N. J., who turned the attention of American scientific men to kite-flying, and created the widespread interest in kites which exists to-day. About 1890 Mr. Eddy lifted thermometers with an ordinary kite, but soon afterwards devised a tailless kite, resembling the Java kite except that the horizontal cross-piece is nearer the top of the vertical stick, and its ends are bent backward in a bow and connected by a cord. This kite starts upward on being held in the wind at the end of a taut line, and continues to rise until the increasing wind-pressure on the portion above the cross-stick balances the pressure on the larger lower portion. The kite is kept from falling to one side by the looseness of the covering on either side of the backbone, and if there is more material on one side than on the other, or if the covering is too tight to form pockets in the wind, the kite requires a tail.[1]

[1] A tail will prevent any kite from turning over, or "diving," because its weight keeps the lower end down while the pressure of the wind on the tail also pulls the lower

In 1891 Mr. Eddy lifted a minimum thermometer by several of these kites flown tandem, and proposed to obtain in this way data to forecast the weather. In the *Proceedings of the Aeronautical Conference*, held in connection with the Chicago Exposition, Prof. M. W. Harrington, then Chief of the U. S. Weather Bureau, quoted Mr. Eddy's estimate of the cost of exploring the air by means of kites flown in series, and advocated their use.

Up to this time it does not appear that self-recording instruments—that is to say, those which make continuous graphic records—had been raised by kites. In the days of the early experimenters such instruments were too heavy and cumbersome to be lifted by the more or less unmanageable kites, but within the past few years M. Richard of Paris has made the simple and light recording

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end backward and maintains the necessary angle of the kite to the wind, the most efficient angle being about 22 degrees. Bending back the ends of the cross-stick gives stability to a kite because, when, on account of the eddies in the wind, a stronger pressure is exerted on one side of the kite, this side is driven backward, thereby presenting less effective surface to the wind, while as the other side comes forward more nearly at right angles to the wind, it receives greater pressure than before. In this way the equilibrium about the central stick is automatically maintained, the required inclination to the wind being secured by the greater surface presented to the wind below the point of attachment of the bridle.

instruments described in connection with balloons, which can be attached to kites. In this way it is possible to obtain simultaneous records at the kite and at a station on the ground, and from them to study the differences of temperature and humidity, and this seems to have been done first at Blue Hill Observatory. In August 1894 Mr. Eddy brought his kites to Blue Hill and with them lifted a Richard thermograph, which had been partly reconstructed of aluminium by Mr. Fergusson so that it weighed but 1¼ lbs., to the height of 1500 feet, and so the earliest automatic record of temperature was obtained by a kite. During the next summer, Mr. Eddy assisted again in the experiments at Blue Hill, and secured photographs of the Observatory and the hill by a camera carried between his kites to the height of a hundred feet or more.

Now that the possibility of lifting self-recording meteorological instruments to considerable heights had been demonstrated, an investigation of the thermal and hygrometric conditions of the free air was undertaken by the staff of the Blue Hill Observatory, who had already made an investigation of the movements of the clouds by the methods described in the second chapter.

The development of the kite and its accessory apparatus, and the acquisition of the knowledge

how to use them, required much time, and resulted in the damage or loss of many kites. Two meteorographs, as the combination of two or more self-recording instruments is called, were dropped from a great height and no trace of them was found. When, however, by the breaking of the line both kites and instrument are carried away, the kites act as a parachute and bear the instrument gently to the ground, where both are usually recovered uninjured; to facilitate their return should they fall at a distance, the name and address are marked on each. It would be tedious to relate the ups and downs of scientific kite-flying at Blue Hill before the wind was successfully harnessed to the service of science, and the kites were prevented from kicking over the traces, or from breaking away, so only a brief account of the progress of the work will be given, and then the methods at present used will be described. At first the Eddy, or Malay kites, as they are also called, covered with paper or with varnished cloth, were coupled tandem to secure greater safety and lifting power. The principle of attaching kites at several points on the line was early adopted at Blue Hill, for although it can be demonstrated theoretically that a greater height is possible by concentrating all the pull at the end of the line, yet in the case of a line which is not infinitely strong the best

results are got by distributing the pull, and in this way, too, kites can be added as the wind conditions aloft warrant. To obviate the frequent breaking of the bowed cross-piece, Mr. Fergusson made it in two pieces, each being held in a metal socket on the central stick, the two pieces forming a dihedral angle towards the wind. It had the advantage also of being readily taken apart for transportation. This kite, shown in Fig. 8, flew at a high angle above the horizon and through a considerable range of wind velocity, but it could not be kept permanently in balance, or made to adjust itself to great variations in wind velocity, and therefore it was discarded.

The first meteorograph, a combined recording thermometer and barometer (from which the height can be calculated), was constructed by Mr. Fergusson in August 1895, and three months later he united a recording anemometer to the thermometer, which was probably the first apparatus of this kind to be attached to kites. A meteorograph, recording the atmospheric pressure, air temperature, and relative humidity, was ordered from M. Richard of Paris in 1895, like one already carried by French aeronauts, except that, since for kites lightness is all-assential, M. Richard constructed this triple-recorder for the first time of aluminium, and hereby reduced its weight to 2⅘ lbs.

One of these meteorographs was hung to a ring at the point of attachment of the two kite-lines to the main line, a method which was used until recently.

FIG. 8.—Eddy tailless Kite.

In August 1895, besides the Eddy kites, there was first used the cellular or box kite, invented by Lawrence Hargrave of Sydney, Australia, which bears no resemblance to the conventional forms of

kites and which it would not be supposed could fly. As seen from Fig. 9 its appearance is that of two light boxes without tops or bottoms, fastened some distance above each other. The wind exerts its lifting force chiefly upon the front

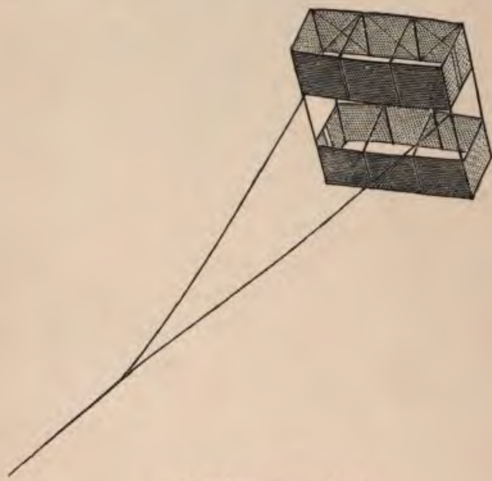

FIG. 9.—Hargrave Kite.

and rear sides of the top box, the lower box, which inclines to the rear, and so receives less pressure, preserving the balance. The ends of the boxes, being in line with the wind, keep the kite steady and serve the purpose of the dihedral angle in the Malay kite. The Japanese are said to fly a single

box, which is the prototype of the Hargrave double cell.

At the present time some form of the Hargrave kite is generally employed for scientific purposes. On account of the weight of the large cord necessary to control these kites, and the surface which it presented to the wind, a height of 2000 feet could not be reached, so, during the winter of 1895-6, following Archibald's example and the methods of deep-sea sounding employed by Captain Sigsbee, U. S. N., steel pianoforte wire was substituted for the cord. This wire is less than half as heavy, and less than one-fourth the size of cord having the same strength, and, moreover, its surface is polished, which reduces the friction of the wind blowing past it. With the wire the height of a mile was reached in July, and a mile and two-thirds above Blue Hill in October 1896.

Up to this time a reel turned by two men sufficed to draw down the kites, but the increasing pull and length of wire made recourse to steam-power necessary. In January 1897 a grant of money was allotted from the Hodgkins Fund of the Smithsonian Institution for the purpose of obtaining meteorological records at heights exceeding ten thousand feet, and no doubt the first application of steam to kite-flying was the winch built by Mr. Fergusson with ingenious devices for dis-

tributing, oiling, and measuring the length of wire. The cumulative pressure of the successive coils of wire finally crushed the drum, and the next apparatus applied the principle of Sir William Thomson's deep-sea sounding apparatus, in which there is no accumulation of pressure. In October 1897 records were brought down from eleven thousand feet, or a thousand feet above the prescribed height.

The kites and apparatus at present employed at Blue Hill will now be described.

The kites are all of the multiplane type, and mostly of Hargrave's construction with two rectangular cells. These cells are covered with cloth or silk, except at their tops and bottoms, and one is secured above the other by four or more sticks. The wooden frames are as light as possible, but are made rigid by guys of steel wire that bind them in all directions. The average weight is about two ounces a square foot of lifting surface, which is about the same weight a square foot as the Eddy kites when all the surface is included in the estimate. The largest of the Hargrave kites stands nine feet high, weighs eleven pounds, and contains ninety square feet of lifting surface, which in the recent kites is arched, resembling the curvature of a bird's wings, a construction that was proposed many years ago by Phillips (Fig. 10).

These curved surfaces increase the lift, or upward pull, more than the drift, or motion to leeward, and so the angular elevation is augmented without materially adding to the total pull on the wire,

FIG. 10.—Modified Hargrave Kite at Blue Hill.

which should not exceed one-half its breaking strength.

Perhaps the most important factor in the success of the Blue Hill work was the invention by Mr. Clayton of the regulating bridle which is applied to every kite. An elastic cord is inserted in the lower part of the bridle, to which the flying-line is attached, and when the wind-pressure increases

this cord stretches, and causes the kite to diminish its angle of incidence to the wind until the gust subsides. A kite can be set to pull only a fixed amount in the strongest wind, when the kite will fly nearly horizontal. We are therefore able to calculate the greatest pull which can be exerted on the wire by all the kites. With this device the kites have flown through gales of fifty or sixty miles an hour without breaking loose or injuring themselves. Another efficient kite which has been used at Blue Hill is the so-called "aero-curve kite" made by Mr. C. H. Lamson of Portland, Maine. As is seen from Fig. 11, this kite resembles a soaring bird, and it can be taken apart and folded up for storage or transportation.

In general, the angle of the flying lines of the Blue Hill kites is 50° or 60° above the horizon, and in winds of twenty miles an hour the pull on the line is about one pound for each square foot of lifting surface in the kite. Kites can be raised in a wind that blows more than twelve miles an hour at the ground, and as the average velocity of the wind for the year on Blue Hill is eighteen miles an hour, the days are few when kites will not fly there.

The wire to which the kites are attached is steel music-wire, $\frac{32}{1000}$ of an inch in diameter, weighing fifteen pounds a mile, and capable of withstanding

a pull of three hundred pounds. The wire is spliced in lengths of more than a mile with the greatest

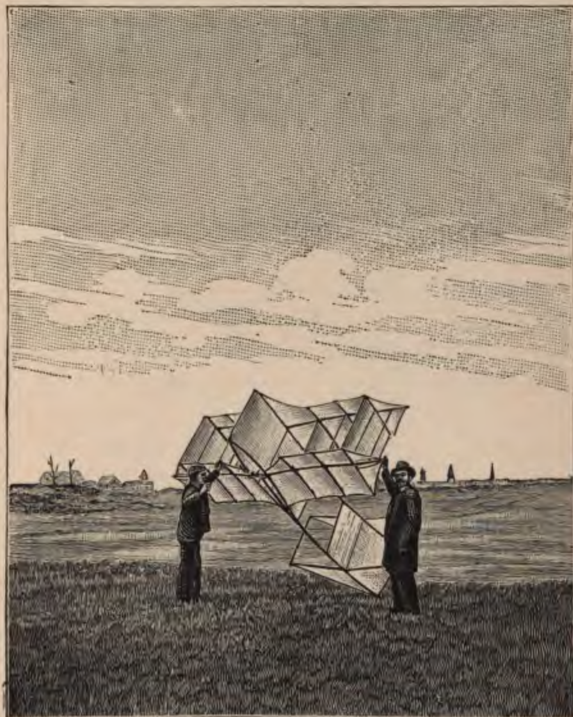

FIG. 11.—Lamson's Aero-curve Kite.

care, special pains being taken that no sharp bends or rust-spots occur which would cause it to break.

To lift the increasing weight of wire, kites are attached at intervals of a few thousand feet, so that the angle may be maintained as high as is consistent with a safe pull, and this is done by screwing on the wire aluminium clamps, to which the kite-lines are fastened. On account of the greater stability and strength of the new kites, the meteorograph is suspended directly from the top kite. The Richard meteorograph, contained in an aluminium cage of about a foot cube, weighs less than three pounds, and it is only necessary to screen the thermometer from the sun's rays to obtain the true temperature of the air, since the wind insures a circulation of air around the thermometer. Another meteorograph, constructed by Mr. Fergusson, records the velocity of the wind in addition to the three other elements, and it weighs no more than the French instrument.

The reeling apparatus is an example of how the same apparatus may serve diametrically opposite purposes. In sounding the deep sea the wire must be pulled upwards, whereas in sounding the heights of the atmosphere the wire must be pulled in the reverse direction. Therefore the deep-sea sounding apparatus has been altered by Mr. Fergusson to pull obliquely downwards, the wire passing over a swivelling pulley which follows its direction and registers on a dial the exact

length unreeled. Next the wire bears against a pulley carried by a strong spiral spring, by which the pull upon it at all times is recorded on a paper-covered drum turned by clockwork. The wire passes now several times around a strain-pulley, and finally is coiled under slight tension upon a large storage-drum. When the kites are to be pulled down, the strain-pulley is connected with a two-horse-power steam-engine, and the wire is drawn in at a speed of from three to six miles an hour; but when the kites are rising the belt is removed, and the pull of the kites unreels the wire.

The method of making a kite-flight for meteorological purposes at Blue Hill is as follows: a kite, fastened by a long wire to the ring in the main wire, being in the air, and the meteorograph suspended, another kite is attached to the ring by a shorter cord (Fig. 12). They are then allowed to rise, and to unreel the wire, until its angle with the horizon becomes low, when, by means of the clamps described, other kites are added, the number depending on the size of the kites and the strength of the wind. After a pause at the highest attainable altitude, the winch is connected with the steam-engine and the kites are drawn down. The pauses at the highest point, and when kites are attached or detached, are necessary to allow the recording instruments to acquire the conditions of the surrounding

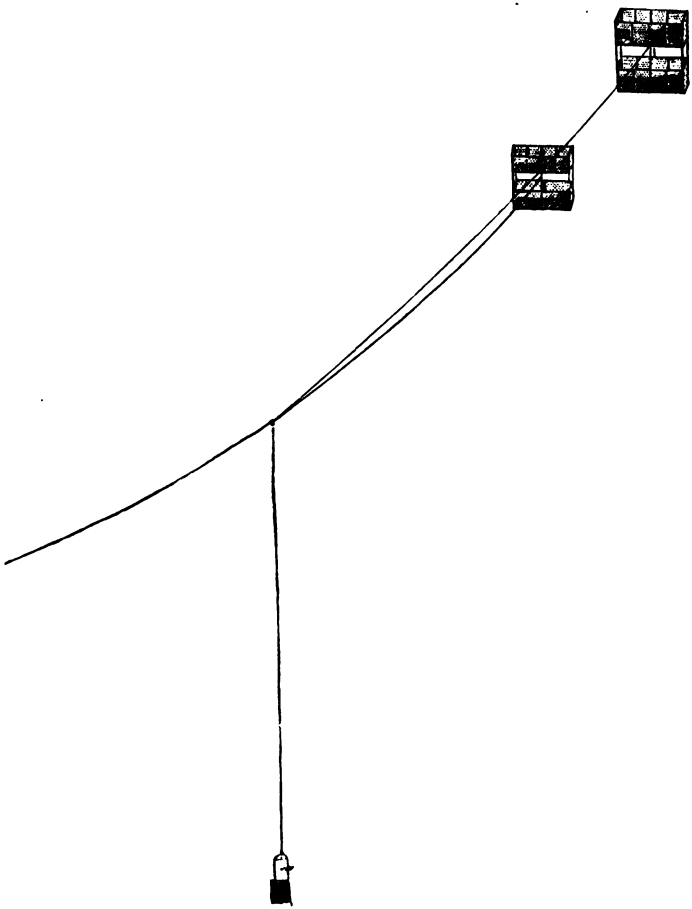

Fig. 12.—Meteorograph lifted by Kites at Blue Hill.

air; and because at these times the meteorograph is nearly stationary, measurements of its angular elevation are made with a surveyor's transit, while observations of azimuth give the direction of the wind at the different heights. The time of making each angular measurement is noted, so that the corresponding point on the trace of the meteorograph may be found. From the length of the wire and its vertical angle, the height of the meteorograph can be calculated, it having been found that the sag of the wire, or its deviation either in a vertical or a horizontal plane from the straight line joining the kite and the reel, does not cause an error exceeding three per cent. in the height so computed. When the meteorograph is hidden by clouds, the height above the last point trigonometrically determined is computed from the barometer record by Laplace's formula. At night there is only the barometer from which to determine the height; for although an attempt was made to use a lantern to sight upon, yet it soon became invisible, or, when seen, was confounded with the stars. Before and after the flight the meteorograph is hung upon a tripod in the free air, in order that its thermometer and hygrometer may be compared with the standards.

Since the use of wire and more efficient kites, the heights have been greatly increased. Thus

the average height above the hill attained by the meteorograph in thirty-five flights made during 1898 was more than a mile and a quarter, whereas the average height of all the ascents prior to 1897 was about a quarter of a mile (see Table). The

HEIGHTS ABOVE SEA-LEVEL OF KITE-FLIGHTS.

(*Blue Hill is* 630 *feet above the sea*)

Year	No. of Records	Heights in Feet		Percentages of Records above				
		Mean of Maximum	Absolute Maximum	500 m. (1640 ft.)	1000 m. (3280 ft.)	1500 m. (4920 ft.)	2000 m. (6560 ft.)	3000 m. (9840 ft.)
1894	2	1,860	2,070	50	0	0	0	0
1895	28	1,673	2,490	59	0	0	0	0
1896	86	2,772	9,327	78	28	9	4	0
1897	38	4,557	11,716	95	68	45	21	5
1898	35	7,350	12,070	100	92	80	66	20

average height of the meteorograph above the hill, in all the flights during August 1898, was nearly a mile and a half, and on August 26 the meteorograph was raised 360 feet higher than ever before, its altitude, determined trigonometrically, being 11,440 feet above Blue Hill, or 12,070 feet above the neighbouring ocean. The meteorograph was suspended from the topmost kite, one of the Lamson pattern, having 71 square feet of lifting surface, and this was increased to a total of 149 square feet by four kites of the modified Hargrave type, that were attached at intervals to the wire. The five miles of wire in the air weighed 75 lbs.,

and the total weight including kites and apparatus was 112 lbs. The meteorograph left the ground at 10:40 a.m., attained its greatest height at 4:15 p.m., and returned to the ground at 8:40 p.m., a feat which it would be difficult for a man to equal on a mountain. The cumulus clouds were traversed three-quarters of a mile from the earth, and above them the air was found to be very dry. On the hill the air temperature was 72°, when it was 38° in the free air 11,440 feet above, and the wind velocity increased from twenty-two to forty miles an hour. These figures give an idea of the change of atmospheric conditions which occurs, but the conclusions deduced from the Blue Hill kite-flights will be discussed in the next chapter. However, the phenomena of atmospheric electricity, which have become noticeable since the use of wire, may be described here. Generally, whenever the kites rise above seventeen hundred feet, the wire becomes strongly charged with electricity, and when the great heights are reached the electricity is discharged in long and brilliant sparks at the reel, often to the inconvenience of the attendants. Usually, the electrical potential increases with altitude, and it is greatest during snow-storms or when the conditions favour thunder-storms. Notwithstanding its intensity, the quantity of electricity in the atmosphere is probably insufficient to make

its collection and storage for practical purposes worth while.

It must not be imagined that kite-flying for meteorological purposes is a sinecure. At Blue Hill about two hundred flights have been made in all seasons and in all weathers, with temperatures varying from $-5°$ to $+90°$, in gales, in rain, and in snow-storms, though not in thunder-storms. Sometimes the kites are invisible from almost the time they leave the earth until their return, but when the upper kites are visible it is necessary to observe them with theodolites every few minutes. Remembering that a high flight occupies ten or twelve hours, and frequently terminates late at night, or even continues until morning, it will be obvious that the work requires skill, energy, and perseverance, which have been shown by my assistants at the Blue Hill Observatory who have conducted the flights.

Occasionally, for lack of wind or from breakage of the line, the kites fall to the ground, usually intact. If they were visible, trigonometrical measurements on the hill enable the place of descent to be located, and then the kites and meteorograph are sent for and the wire is reeled up. But at night, or when clouds hide the kites, the direction in which they fall is not known, because the azimuth of the wire at the reel often differs from

that of the kites; so last autumn several hundred miles of road, path, wood, and swamp were traversed before the aërial apparatus, which had been lost during a flight at night, was found comparatively close at hand.

From what has been said it will be evident that a former toy has been proved to be of the greatest importance for meteorological investigation at the Blue Hill Observatory. On account of the success there attained it is coming into use elsewhere for meteorological observations. In 1898 the United States Weather Bureau created seventeen kite stations, chiefly in the Mississippi Valley, with the intention of obtaining data every day, at the height of a mile or more, with which to plot a synoptic weather map similar to the map that is now drawn from the data at the ground. From a knowledge of the weather conditions prevailing simultaneously in the upper and lower air, it was expected that the weather forecasts could be improved, but unfortunately, on account of the light winds during the summer, it was impossible to make enough simultaneous kite-flights to construct the upper-air map, and therefore the scheme was abandoned. However, the data obtained will no doubt furnish valuable information about the vertical temperature gradient, etc., in various conditions of weather. The chief meteorological bureaus of Germany and

Russia are equipping stations with kites and balloons, and M. Teisserenc de Bort, who has provided his private observatory near Paris with kite apparatus of the Blue Hill type, has already reached high altitudes. In Scotland too, which was the birthplace of scientific kite-flying, experiments have been resumed by a Scotchman and an American—a happy union of forces.

From these preparations it appears that the resolution of the International Aeronautical Conference, recommending that all central observatories should employ this method of investigation as being of prime importance for the advancement of meteorological knowledge, is being carried out, and seems likely to produce important results.

CHAPTER VI

RESULTS OF THE KITE-FLIGHTS AT BLUE HILL—FUTURE WORK

KITES possess several advantages over other methods of exploring the air up to heights of at least 12,000 feet whenever there is wind, but their chief merit is, that with them the true conditions of the air may be ascertained. The disadvantages of other methods of exploring the air, as compared with kites, are these :

1. **Mountains** not only affect by contact the adjacent air, but by deflecting the air-currents cause mixture and ascent, which give conditions differing widely from those of the free air.

2. **Free Balloons** are more or less surrounded by heated or stagnant air, because they drift with the wind, and on account of the sluggishness of the thermometers, the temperatures observed at a given height in a balloon are generally higher during the ascent, *i.e.* when passing from warm to cold air,

than during the descent, when the conditions are reversed. Again, it is not possible to study the progressive changes in the atmospheric conditions at one place, because observations in a drifting balloon are not comparable with simultaneous ones made at a station on the ground below. With kites, however, the possibility of making frequent and nearly vertical ascents and descents permits observations to be obtained almost simultaneously in superincumbent strata of air. The height of the kite can usually be determined with an accuracy not attainable by the barometer in a balloon.

3. **Captive Balloons**, although constructed so as not to be driven down by wind, cannot rise nearly so high as kites on account of the weight and resistance of the cable necessary to control them, and even the German kite-balloon, on account of its large surface, would hardly withstand the strong winds in which kites can fly.

4. **The Cost** of installing and operating either mountain stations or balloons is much greater than for kites.

The exploration of the lower two miles of air with kites flown from Blue Hill is no doubt the most complete ever made at one place. Nearly two hundred records have been obtained in all kinds of weather-conditions, and the progressive attainment of greater and greater heights is shown in the

table in the preceding chapter. The records from the flights have been discussed by Mr. Clayton; those until February 1897, with the Blue Hill Observations, in Vol. xlii., Part I., of the *Annals of the Astronomical Observatory of Harvard College*, and later records in two *Bulletins* of the Blue Hill Observatory, in which the changes of temperature and humidity with height, and their relation to the positions of cyclones and anti-cyclones, are investigated. The use of kites for weather predicting, as was said, has been tried by the United States Weather Bureau, but it is certain that further studies, such as have been made on Blue Hill, are necessary before the sequence of the conditions at the earth's surface to the phenomena observed in the upper air is definitely known, so that the latter can be utilized in forecasting.

Some of the deductions from the observations with kites at Blue Hill follow. Plate VIII. is a facsimile of the record of the baro-thermo-hygrograph during two flights on October 8, 1896, when for the first time the height of a mile and a half was attained. The record-sheet, it may be said, is wrapped around a cylinder that turns on its axis in twelve hours, and the curved lines in each of the three horizontal sections divide them into quarter hours. The lower section contains the trace of the barometer, the horizontal lines being the heights in

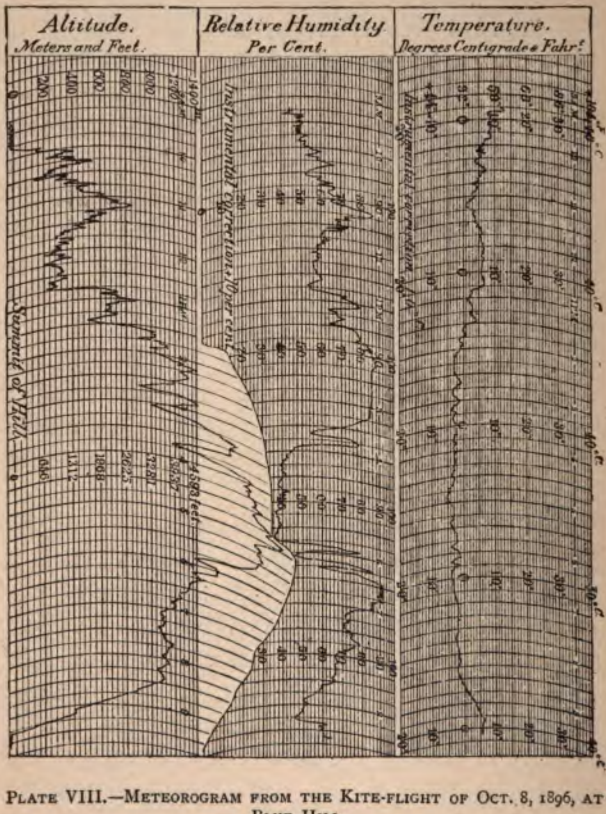

PLATE VIII.—METEOROGRAM FROM THE KITE-FLIGHT OF OCT. 8, 1896, AT BLUE HILL.

metres and feet that correspond to the barometric pressure with a temperature of 32° Fahrenheit; in the middle section is the trace of the hygrometer on a scale of relative humidity in percentages, and in the upper section is the trace of the thermometer on a scale of temperatures in Fahrenheit and Centigrade degrees. It will be observed that the record of the barometer is reversed, *i.e.* the trace rises for falling pressure, and in the second flight when the unexpected height of 8697 feet above Blue Hill was reached, the limit of the altitude scale was exceeded.

In order to study the changes of these elements with height during the higher flight, in Plate IX., Figs. 4 and 5, the temperature and humidity of the automatic record are plotted as abscissæ, with the heights above sea-level in metres as ordinates. For those not familiar with this unit of length, it may be said that 100 metres are about 330 feet, and that 1600 metres equal one mile approximately. When the meteorograph was ascending, dots indicate the recorded temperatures and humidities, which are each connected respectively by continuous lines; when the meteorograph was descending, crosses indicate the observations, which are connected by broken lines. Lines inclining upwards to the left indicate decreasing temperature and humidity with increase of height, and lines inclining to the right

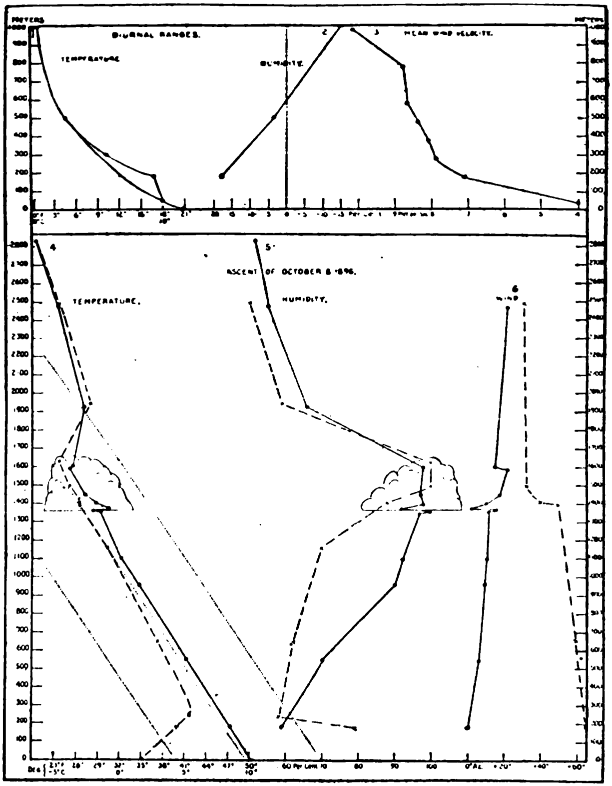

PLATE IX.—MEAN CHANGES WITH HEIGHT, AND CHANGES DURING THE KITE-FLIGHT OF OCT. 8, 1896.

increasing temperature and humidity with height. The straight dotted lines show the adiabatic decrease of temperature for ascending dry air. The ascent was made during the warmest part of the day, and the descent for the most part after sunset. The two branches of the temperature-lines typify the temperature change with height which usually occurs in fair weather during the day and the night respectively. The continuous line, representing the day observations, shows a uniform fall of temperature at the adiabatic rate to the cloud level. During the night, the lower part of the broken line bends decidedly to the left, showing a body of relatively cold air near the ground, caused by radiation. There is a rise of temperature with increasing altitude above the ground up to a certain height, and afterwards a comparatively uniform fall as high as the clouds, if they exist; but the rate of fall with increasing altitude, shown by the upper part of the diagram, is slower at night than during the day. It appears that the diurnal change of temperature is very small at great altitudes, compared with the change near the earth's surface. The relative humidity (Fig. 5) up to 2000 metres varies inversely with the temperature, and in the present case there was only a slight change in the direction of the wind (Fig. 6).

Diurnal Changes of Temperature at Different

Altitudes.—The curve representing the diurnal change in the air at some distance above the ground is probably similar to one representing the change near the ground, except that its amplitude is less. If this be true, then the diurnal rate of fall for a given time at any two levels will be proportional to the daily ranges of temperature at the two levels. It is impossible in practice to keep a kite at exactly the same level for twenty-four hours; hence the daily ranges for the different levels must be found by comparing the rates of rise or fall of temperature for given times with the rates found from records near the ground, made simultaneously with those above. In Plate IX., Fig. 1, the results for six stations, *i.e.* the kite at 1000 and 500 metres, the Eiffel Tower in Paris (300 metres), the summit of Blue Hill, its base, and the valley (200, 50, and 15 metres respectively), are connected, and a smooth curve is drawn through them. The curve passes approximately through every one of the observed and the computed ranges, except the one at the summit of Blue Hill, which is too great. This evidently is because insolation and radiation, acting through the soil of the hill, heat and cool the air to a greater extent than the free air is heated and cooled at the same altitude, and this must be true at every mountain station. The smoothed curve passes also very slightly to the left of the data for

the Eiffel Tower, indicating that the range there is about 1° greater than the true range on account of the heating and cooling of the Tower. From this it appears that the diurnal range of temperature diminishes rapidly with increasing altitude in the free air, and almost disappears in the average at a height of 1000 metres.

The records of the anemometer show that, as a rule, the wind increases steadily as the kites rise, but the increase is greatest between Boston and the top of Blue Hill, due probably to the retarding of the lower winds by contact with the ground. The results are plotted in Plate IX., Fig. 3, together with the mean wind velocity on Blue Hill (209 metres), and the velocity on a tower in Boston (60 metres). Single records of the kite-anemometer differ much, for sometimes the wind velocity diminished with altitude, and at other times it increased so rapidly that the kites were unable to rise higher. On several occasions when the kites passed from one current into another, having a different direction and a different temperature, the wind suddenly increased, and was stronger between the two currents than above or below that plane.

Diurnal Changes of Humidity at Different Altitudes.—It is found that as night approaches the humidity at the altitude of 1000 metres diminishes, while at the earth it increases. This agrees with

the evidence furnished by the cumulus clouds that form during the day between 1000 and 2000 metres, and disappear at night, thus visibly indicating an increase of humidity by day and a decrease by night. If the trend of the humidity-curve at a height of 1000 metres is assumed to be the reverse of its trend at the ground, then the results from the kite-meteorograph show the minimum humidity to be at the coldest and the maximum humidity at the warmest part of the day. The mean daily ranges for different altitudes are plotted in Plate IX., Fig. 2. The part of the curve at the left of the zero line shows the range at different altitudes, with the minimum humidity near the warmest time of day, while the part at the right of the zero shows the ranges at different altitudes, with the minimum humidity at the coldest time of day.

Types of Change of Temperature with Altitude.— When the records of temperature and humidity made aloft by the kite-meteorograph and at the stations near the ground are plotted in relation to altitude, they are found to be easily divisible into a few types. In Plate X., Type 1 represents the decrease of temperature on most fair days from the ground to altitudes of a mile or more, when no clouds are met. The continuous line, plotted from the records of the ascent, represents the day

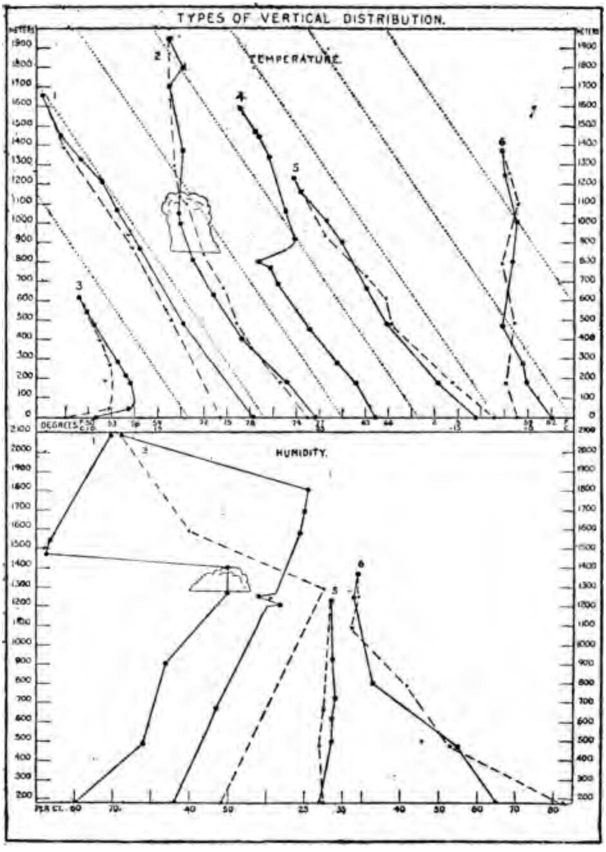

Plate X.—Changes with Height recorded by Kites at Blue Hill.

conditions, and the broken line, plotted from the records of the descent, represents the night conditions. This curve shows that with increasing altitude the temperature falls uniformly during the day and approximately at the adiabatic rate represented by the dotted lines. The fall of temperature with increasing altitude during the night is slower than during the day, and in fact, from the earth's surface to an altitude of a few hundred metres, there is often a rise of temperature with height, so that the air at altitudes of from 300 to 500 metres may be considerably warmer than it is at the ground. This was shown in the descent on October 8, 1896, and is found in Type 3.

When clouds are traversed during the flight, the temperature curve assumes the form of Type 2. The continuous curve is plotted from the records of an ascent; the broken curve from the records of the descent, both occurring in the day-time. The temperature falls at the adiabatic rate in unsaturated air till the base of the cumulus cloud is reached. It falls at a slower rate in the cloud, the rate probably being that computed by physicists as the adiabatic rate for air in which condensation is taking place. Above the clouds, the fall of temperature appears to be very slow.

Type 3 is a condition which persists throughout the day and night, and it resembles the night form

of Type 1. The temperature rises very rapidly for a short distance above the ground and then falls, with increase of height, somewhat slower than the adiabatic rate. The rise of temperature near the ground with increasing height is more marked after sunset than during the day-time.

Type 4 was illustrated by the ascent of October 8. This distribution of temperature is caused by a warmer current overflowing colder air, which is very commonly found at low altitudes in the atmosphere and probably exists usually at some altitude, great or small. Recent observations indicate that this type represents the normal condition of the atmosphere in all sorts of weather. Frequently there are two or more sudden rises of temperature at different heights, so that the plotted data resemble inverted stair-steps. During the day there is a decrease of temperature at the adiabatic rate ($1^{\circ}\cdot 8$ in 100 metres) from the ground to the height of several hundred metres, then a sudden rise of temperature in the next one or two hundred metres, and above this a slow fall of temperature with increasing altitude, usually much less than the adiabatic rate. Generally, clouds are found near the plane of meeting of the warm and cold current.

The reverse of Type 4, that is, a sudden fall of temperature, due to a colder current overlying a warmer one, is probably impossible, because the

colder air, on account of its greater weight, would immediately begin to sink and the warmer air would rise. This should cause a fall of temperature at the adiabatic rate from the ground to the top of the colder current, and is probably the origin of the "cold wave" shown in Type 5. Both the continuous and broken curves (representing an ascent and a descent) show a fall of temperature at the adiabatic rate of unsaturated air, from about 500 metres to the highest point reached. Up to 500 metres the decrease of temperature is more rapid than the adiabatic rate, due to the rapid moving in of colder air above, whereby air rising from the ground is cooled by contact as well as by its expansion, and also because the air is heated more than usual by contact with the ground, which under these conditions is abnormally warmer. This is the special characteristic of the "cold wave" type of curve during the day hours. The night form of Type 5, notwithstanding the excessive radiation from the ground through the dry air, shows a rapid decrease of temperature with increase of altitude from the ground upward.

Type 6 shows a less common, but an interesting form, of vertical distribution of temperature, in which the temperature is about the same from 400 metres to 1400 metres or more. Up to 400 metres there is a fall of temperature with increasing alti-

tude during the day, and a rise with increasing altitude at night. These last conditions can be readily traced to the effects of insolation and radiation near the ground. In the morning, if the temperature of the air be the same from the ground up to 1000 metres or more, the heating of the ground by the sun will cause ascending currents, until the warmest part of the day. This air, cooling by expansion at the adiabatic rate, will rise to about 440 metres before it assumes the mean temperature of the upper air column. At night cooling takes place next the ground by radiation and is gradually transferred upward a few hundred metres by conduction, thus producing an increasing temperature with increasing altitude, until sunrise. As a result of the conditions described, it is evident that on certain days the diurnal range of temperature is but little felt above 500 metres.

Types of Change of Relative Humidity with Altitude.—As in the temperature types, the continuous lines represent the records of the ascent, and the broken lines the records of the descent, generally under changing conditions. Lines inclining upward to the left show a decreasing humidity, and to the right an increasing humidity.

Type 1 may be called a normal type of curve when there are clouds. A variation of this type was met with in the ascent on October 8, 1896,

and it differed from that now illustrated in indicating in its upper part a fall of humidity rather than a rise. These two types can be taken as the normal change of humidity with change of altitude in cloudy or partly cloudy weather. The humidity increases steadily to the base of the cloud, then there is complete saturation in the cloud, and above it is a sudden fall of humidity, on entering the dry air above the cloud, into which the ascending currents from the ground have not penetrated.

Type 3 is a clear-weather form of curve in which the humidity increases until a certain altitude is reached, probably at the upper limits of the currents rising from the ground. Above this altitude the humidity decreases rapidly.

Type 5 is also a clear-weather form and accompanies the "cold wave" type of temperature, also numbered 5. The very dry descending air mingles with air rendered damp by ascent, and the result is a nearly uniform relative humidity at different altitudes, although the absolute humidity diminishes on account of decreasing pressure and temperature. In Type 6 both the relative and the absolute humidity decrease rapidly, this type coinciding with the temperature, Type 6.

During the week of September 5 to 11, 1897, kite-flights were made daily on Blue Hill. Twice the kites were maintained in the air, and continuous

records were obtained during most of twenty-four hours. These records furnish an example of the small diurnal changes of temperature in the free air at short distances above the ground, which were deduced from the average changes at different hours and at different heights. From 2 p.m. of the fifth to 2 p.m. of the sixth, the altitude of the self-recording instruments varied between 500 and 1000 metres above sea-level, averaging about 700 metres and varying little from this height during much of the night. The times when the kite-meteorograph crossed the 700-metre level in ascending and descending were determined from its barograph trace, and the synchronous temperatures and humidities were read from the records of its thermograph and hygrograph. The results have been plotted in Plate XI., Figs. 1 and 2, together with the temperatures recorded simultaneously at the summit and valley stations of the Observatory and the humidities at the summit. Fig. 1 shows that the diurnal variation of temperature, well marked at the lower levels, is very slight or has entirely disappeared at 700 metres. Fig. 2 shows that the course of the relative humidity at 700 metres is exactly opposite in phase to that recorded at lower levels, for at 700 metres the minimum humidity was recorded at night and the maximum during the day, while the opposite conditions prevailed on

the hill. Repeated kite-flights indicate that these are the normal conditions at the two levels.

In Plate XI., Fig. 3, is plotted a curve from the hourly readings of the thermograph at the Blue Hill valley station (fifteen metres) during the week, and also a curve connecting temperatures recorded by the kite-meteorograph once or twice each day during the same week at a level of 500 metres, obtained in the way described or computed from the adiabatic change. All the night records show that it was decidedly warmer at the height of 500 metres during the night than it was at the ground, except during the cool wave on the seventh and eighth. Furthermore, the curves in Fig. 3 indicate a control of the surface temperatures during the day by those above. For instance, on the seventh there was a distinct flattening of the day curve, evidently because, as the temperature on the ground rose 10° above that at 500 metres, the air was in unstable equilibrium, and colder air descended to take the place of the surface air so that its temperature could rise no higher. On the tenth, the temperature at 500 metres was considerably greater than the mean of the day at the ground, and the air at the ground did not acquire the unstable condition in any volume until the warmest part of the day, so that the diurnal curve at the lower station forms a sharp peak.

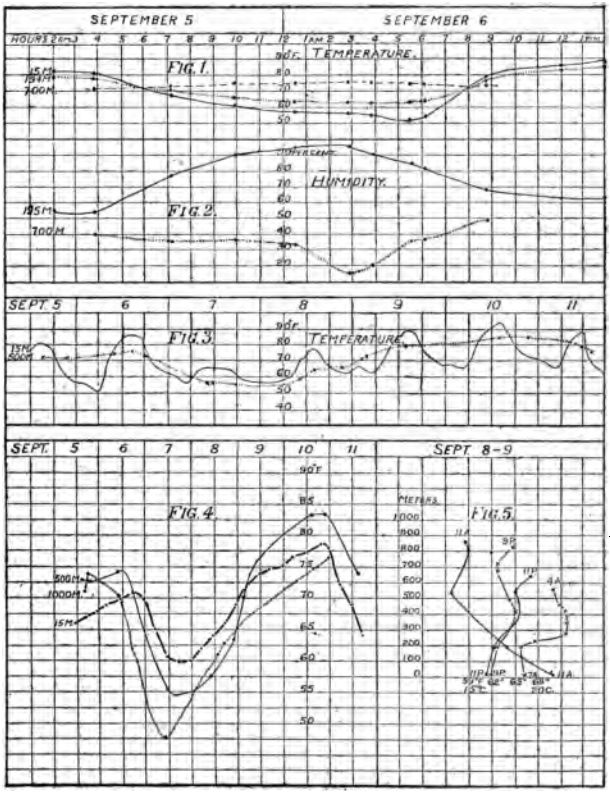

PLATE XI.—KITE OBSERVATIONS AT BLUE HILL, SEPT. 5-11, 1897.

Since there appears to be no appreciable diurnal period in the temperature at and above 500 metres, a better comparison of the relative changes aloft and below during the passage of warm and cold waves is obtained by smoothing out the diurnal period below. This has been done in Plate XI., Fig. 4, with the data given by the kites at 500 and 1000 metres plotted in curves, which it was necessary to complete by extrapolation. It is seen that there is a much greater range in the temperature from the crest of a warm to the crest of a cold wave at a height of 500 metres than at the ground. At 1000 metres the range appears to be slightly greater than at 500 metres, and the crests of the warm and cold waves occur successively earlier than they do at the ground. On the approach, and until the passage of the crest of the cold wave the air is colder aloft than at the ground, the difference being apparently that of the adiabatic cooling of ascending air. After the passage of the crest of the cold wave, the temperature aloft rises much more rapidly than at the ground, and at the crest of the warm wave the air at 500 metres is some 10° warmer than the mean daily temperature at the ground. In many kite-flights the difference was found to be even greater than this. Taking the mean temperature of twenty-four hours, it is seen that the average temperature at the ground

during a week or more is about the same as it is at 500 metres. Fig. 5 shows the change in the vertical distribution of temperature during the oncoming of the warm wave on the eighth and early morning of the ninth, as determined by four ascents, culminating at 11 a.m., 9 p.m., 11 p.m., and 4 a.m. The lines of 59°, 62°, 65°, and 68° show that there was a gradual rise of temperature aloft, which extended downwards to 200 metres, or to the top of Blue Hill. Clouds formed at the level of lowest temperature, and these sank also until they covered the top of the hill.

Plate XII. is a facsimile of the meteorogram during the kite-flight of October 15, 1897, the lower part showing the trace of the barometer on a scale of heights in metres, the middle section the trace of the hygrometer, and the upper one the trace of the thermometer on a scale of Centigrade degrees. The temperature followed the normal change, which is as follows: during the day, up to a certain height, which varies under different conditions, there is a decrease nearly at the adiabatic rate of 1°·8 F. per hundred metres. Above that height the air suddenly becomes warmer, and then cools with ascent at a rate somewhat less than the adiabatic rate. During the night there is a marked inversion of temperature between the ground and 200 or 300 metres.

KITE METEOROGRAM OF OCT. 15, 1897.

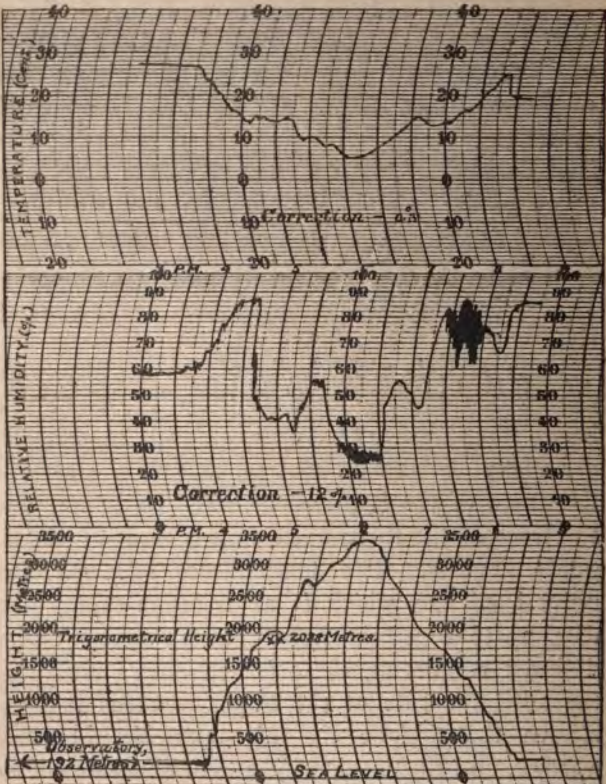

PLATE XII.—AUTOMATIC RECORDS DURING A HIGH KITE-FLIGHT AT BLUE HILL.

Higher than this, the temperature decreases at a fairly uniform rate, but more slowly than the adiabatic rate. Although no clouds were visible, yet the relative humidity increased greatly, both during the ascent and descent, near 1500 and 2700 metres, these being about the heights at which cumulus and alto-cumulus clouds usually form.

During September 1898 four kite-flights were made on four successive days when an anti-cyclone and a cyclone passed nearly over Blue Hill. This is a rare occurrence, and the mechanism of these phenomena was accordingly studied by Mr. Clayton, some of whose deductions will now be given, illustrated by Plate XIII. Figs. 1 and 2 give the temperature plotted according to height on September 21 in the anti-cyclone, and on September 22, when the barometric pressure was falling, the full lines, as in previous diagrams, indicating observations during the ascents, and the broken lines observations during the descents. It is seen that from the ground the lines all incline upward to the left, indicating a fall of temperature, to a certain height when the lines bend to the right sharply, showing a sudden rise of temperature. Above this, the temperature again falls, but more slowly than at lower levels. The general prevalence of this phenomenon was noted by Welsh in his balloon ascents in England in 1854, and the high

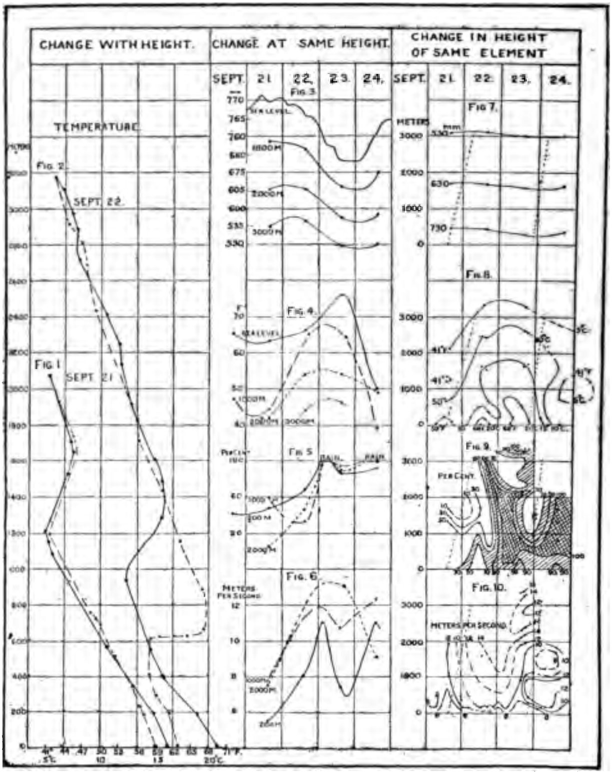

Plate XIII.—Results of Kite-flights at Blue Hill during an Anti-cyclone and a Cyclone.

kite-flights at Blue Hill show it to be very frequent below 2000 metres. The plane of increased temperature usually determines the height of the tops of cumulus and strato-cumulus clouds. Above 2000 metres other sudden rises of temperature are found during the highest kite-flights.

Figs. 3 to 6 show the changes in the various elements during the four days at some of the following levels, viz. near sea-level, 200, 1000, 2000, and 3000 metres. Fig. 3 shows the changes in the barometer at the four levels, from which it is evident that the fall of pressure was greatest near sea-level.

Fig. 4 shows temperature changes at the different levels, and indicates that the changes were of the same nature up to 3000 metres. The greatest non-diurnal range of temperature is seen to be at 1000 metres, and it diminishes both at higher and at lower levels.

Fig. 5 shows changes in relative humidity at 200, 1000, and 2000 metres. The curves show that the greatest range of humidity was at 2000 metres. There the relative humidity rose from almost zero, in the anti-cyclone on the twenty-first, to saturation at the same level in the cyclone. At 200 metres the change is similar to that at 2000, but is less in amount. At 1000 metres the relative humidity fell until the twenty-second, but then rose rapidly,

showing the very dry air at 2000 metres on the twenty-first had descended as low as 1000 metres on the twenty-second.

Fig. 6 gives the change in wind velocity at the different levels. There was an increase of wind at all the levels from the time of the passage of the anti-cyclone to the passage of the cyclone. The minimum of wind at 200 metres was in the anti-cyclone, with a secondary minimum during the passage of the centre of the cyclone.

Figs. 7 to 10 show the changes in height from day to day of the equal conditions at the different levels. Fig. 7 shows the change in level of the isobars, which, although very small, is largest at the lower levels. The light broken lines in Fig. 7 and subsequent figures indicate the axes of the anti-cyclone and cyclone. That the axis of the cyclone was inclined backward, and that the high pressure occurred later at high than at low levels, was confirmed by the wind observations on the twenty-first.

Fig. 8 shows the heights at which the same temperatures were found on successive days. Since the isotherms rose until the twenty-third, the temperature of the air up to 3000 metres was higher on the day of the cyclone than on the day of the anti-cyclone. Previous high flights indicate that this is the normal condition in the moving cyclones

and anti-cyclones of the eastern United States. As the light broken lines represent the axes of the anti-cyclone and cyclone up to 3000 metres, it is seen that at this level the temperature at the place of maximum pressure is probably higher than at the place of minimum pressure, although this is not true for a vertical column of air above the earth.

Fig. 9 gives the positions of equal humidities on successive days, saturated and cloudy areas being indicated by crossed shading, and less humidity by single ruling. From the laws of thermo-dynamics the unshaded curves should represent descending currents, and the shaded portions ascending ones. In the first case, increased warmth and a lower relative humidity are produced in the descent to a lower altitude; in the last case, cooling, increasing relative humidity, and condensation are produced by expansion in the ascent to a higher altitude. Consequently, two regions of descending air are indicated, one in the centre of the anti-cyclone, the other in the centre of the cyclone.

Fig. 10 shows the change in height of the lines of equal wind velocity. With ascending currents and precipitation, high wind velocities were found at low levels, because of increased barometric gradient, while with the descending currents in the anti-cyclone and centre of the cyclone, the high velocities were found only at great altitudes.

The study of these data indicate that the cyclonic and anti-cyclonic circulations observed in this latitude do not embrace any air-movements at greater altitudes than 2000 metres, except in front of the cyclone, when the air appears to be carried upward to a great height. Above 2000 metres there are probably other weak cyclones and anti-cyclones, or secondary ones, with their centres at different places from those at the earth's surface and producing a different circulation of wind. The observations of the cirrus clouds at Blue Hill indicate that at their level exists a cyclonic circulation above the anti-cyclone apparent at the earth's surface. The shallowness of our anti-cyclones would be inferred from the great differences in speed of the general atmospheric drift, for since the velocity of the general drift from the west is more than thirty times greater at 10,000 metres than it is at 200 metres, a circulation of great depth could not endure long. Cyclones and anti-cyclones appear to be but secondary phenomena in the great waves of warm and cold air which sweep across the United States from periodic causes.

The origin of cyclones and anti-cyclones is perhaps the most important problem remaining for meteorological study. The theory that they are produced by differences of temperature in adjacent masses of air, or, as it is called, the convectional

theory of the American meteorologists, Espy and Ferrel, is opposed by the observations on mountains in Europe which were collected by Dr. Hann of Vienna. If the question can be solved by the use of kites, as seems to be foreshadowed by the results just stated, another foundation-stone will be laid in the science of meteorology and the status of the kite established as an instrument of research. The kite fails when there is little or no wind at the ground, but it seems possible in such cases to lift the kite into the upper air, where there usually is wind, by attaching it to a small balloon that, after the kite can support itself, shall be detached automatically. While the height to which kites can rise is limited, and the limit is probably being approached, judging from the less gain of altitude in recent flights, yet it seems reasonable to expect that, with favourable conditions, a height of at least three miles will be reached.

Besides lifting the meteorological instruments described, kites can carry apparatus for other investigations in the free air, such as the measurement of atmospheric electricity, and the collection of samples of air, to be examined for cosmic dust and bacteria. Cameras have been lifted by kites, as already said, and for the purpose of photographing the upper surfaces of clouds there is being constructed for the Blue Hill Observ-

atory a very light automatic camera, similar in principle to M. Cailletet's apparatus for photographing the ground from a balloon.

The use of the kite as an aeroplane can only be alluded to in this book, and it may be sufficient to say that if a motor attached to a kite can, by wings or screws, propel it against the wind, the sustaining string is unnecessary, and we shall have the flying machine which Professor Langley tells us will soon be realized. The surface of our globe has been tolerably well explored; the exploration of the atmosphere by balloons and kites will continue to make great progress during the last year of the century, and at the end of the twentieth century we may confidently expect that as the seas now are a medium for transportation, so the ocean of air will have been brought likewise into man's domain.

INDEX

A

D

E

F

J

K

L

M

N

O

P

R

S

T

U

V

W

Y

Z

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